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Reference

Lane, B. H., 1935. Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C., 25¢.)

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NOVEMBER 1950

LATE PRE-CAMBRIAN OR LOWER CAMBRIAN FORMATIONS IN CENTRAL VIRGINIA

ROBERT O. BLOOMER

ABSTRACT. It is generally believed that there is a significant hiatus between the Catoctin formation and the Chilhowee series. The Catoctin and the concordantly underlying Lynchburg and Swift Run formations are defined as late pre-Cambrian and the Chilhowee as Lower Cambrian. Although the age classification may be correct, there is evidence of a continuous sequence from the base of the Lynchburg into the Chilhowee. This relationship may appear to be refuted where the Chilhowee rests with conspicuous unconformity upon a granitized complex definitely older than late pre-Cambrian. However, this unconformity is an inclined surface that cuts across formation boundaries. The Lynchburg and Catoctin overlap this surface from east to west. Consequently, the absence or restricted thickness of the Catoctin beneath the Chilhowee in certain sections is not due to an interval of erosion between the two formations, but to the location of the sections with respect to the margin of the overlap.

In places, there appears to be a complete section between the Catoctin in the Blue Ridge and the Wissahickon in the Piedmont of central Virginia. No continuous faults, including the Martic overthrust, have been identified despite a painstaking search. In other words, the Catoctin is not everywhere separated from the Wissahickon or the Lynchburg from the Wissahickon by faults.

These relations indicate the presence of a vast thickness of metasedimentary rocks of predominantly terrigenous character interrupted by several thousand feet of greenstone southeast of the Blue Ridge. The metasedimentary rocks above the greenstone are in the Wissahickon formation and those below the greenstone are in the Lynchburg formation. The Wissahickon, therefore, is Paleozoic in age and at least partly equivalent to the Lower Cambrian Chilhowee group of the Appalachian geosyncline. The Blue Ridge is generally recognized as the southeastern margin of this geosyncline. If the Wissahickon is Paleozoic in age as here interpreted, the geosyncline is actually much more extensive and the complex northwest of the Blue Ridge is a foreland trough.

INTRODUCTION

DURING all or part of the past ten summers, the writer has made a detailed study of the Blue Ridge province between James River and Rockfish Gap in central Virginia. Two quadrangles have been mapped on a scale of approxi-

mately one inch to the mile and other areas studied. The work has extended a short distance into the Valley and Ridge province to the northwest and into the Piedmont province to the southeast.

Before the geology of the Blue Ridge and Piedmont provinces can be integrated with the better-known geology of the Valley and Ridge province, the stratigraphic relations of certain formations must be established. One such formation is the Catoctin greenstone and another is the Lynchburg formation.

Bloomer and Bloomer (1947) conclude that the Catoctin and the underlying Swift Run (Oronoco) are older than the Lower Cambrian Chilhowee group, but Cambrian in age. Stose and Stose (1949, pp. 298-299) and King (1949, pp. 636-638) have defined the Catoctin as older than the Chilhowee group, but late pre-Cambrian in age. Excepting the age, there seems to be more agreement than disagreement regarding the stratigraphic relations of the Catoctin formation.

An effort is here made to interpret the relationship of the Catoctin to the overlying Chilhowee group and to the underlying Swift Run and Lynchburg formations. When the relations of these formations are firmly established the paleogeography may be better understood and the location of the boundary at the base of the Cambrian might be more successfully argued.

TABLE I

SEQUENCE OF FORMATIONS IN THE BLUE RIDGE REGION OF VIRGINIA

Southwest of Roanoke	Central Virginia	Northeast of Rockfish Gap	
Erwin	Erwin-Antietam	Antietam	Chilhowee Group — CAMBRIAN
Hampton	Hampton-Harpers	Harpers	
—— Unicoi ——	Unicoi volcanics	Weverton volcanics / Loudoun	
Lynchburg ?	Catoctin / Swift Run (Oronoco) / Lynchburg	Catoctin / Swift Run / Lynchburg	?
	Injection Complex "Granitized Complex"	Injection Complex	Pre-C

LOWER CAMBRIAN FORMATION NAMES

As shown by table 1, one set of names is used for the Cambrian formations southwest of Roanoke and another for the Cambrian formations northeast of Roanoke (Butts, 1940, pp. 26-40). Inasmuch as there is little difference in lithology, stratigraphy, or thickness from southwest of Roanoke at least to Tye River Gap, 64 miles northeast of Roanoke (fig. 1), the present usage of two sets of names for the lower Cambrian formations seems somewhat arbitrary. Indeed, it is confusing. In central Virginia, for example, the Weverton formation is represented by a coarse-grained quartzose facies that forms lenticular bodies, from about 3 inches to 25 feet thick and a few hundred feet long, at irregular intervals in an arkosic sandstone facies that resembles typical Loudoun. The Wever-

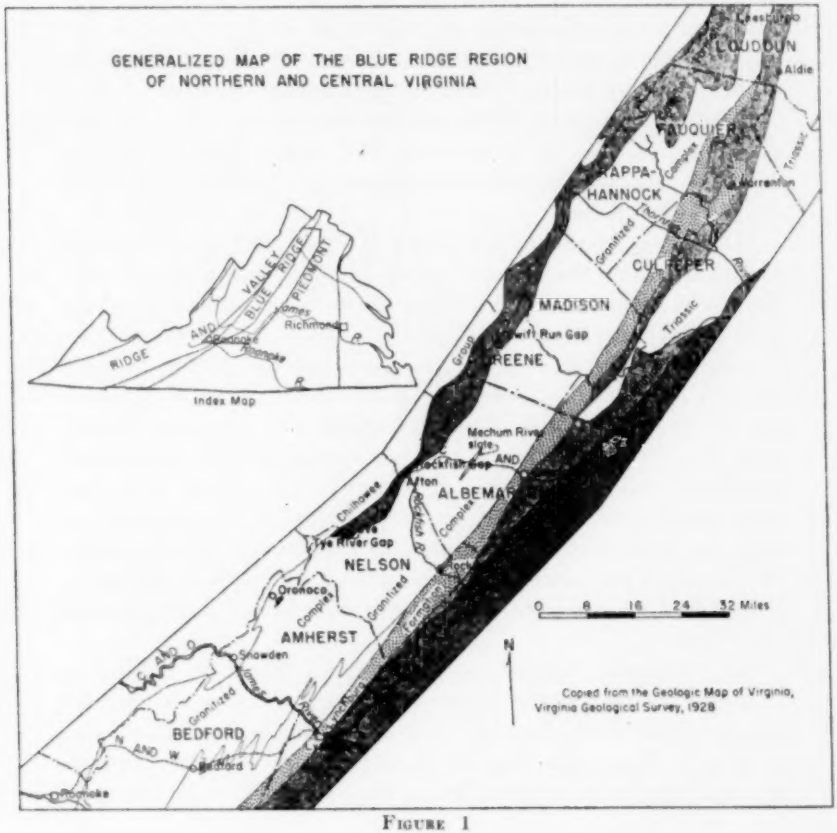


FIGURE 1

ton, consequently, is not a well-defined lithologic unit differentiable as a formation in central Virginia unless all the rocks above the graywacke conglomerates and volcanics at the base of the Chilhowee are Weverton. If this is true, the Loudoun is only about 100 feet or less thick. Furthermore, the quartzose pebble conglomerates characteristic of the Weverton are contained in the basal graywacke conglomerate. Keith (1894, p. 326) refers to places at the north and south ends of Catoctin mountain in northern Virginia where the Weverton is underlain by only a few feet of Loudoun. Although this restriction in the thickness of the Loudoun may be due to overlap or erosion, neither of these explanations seems plausible. The total thickness of the formations appears to be comparatively unchanged so that the presumption is that the Weverton is extended downward at the expense of the Loudoun. Consequently, there seems to be some question of the status of the Weverton even in northern Virginia. Is the Weverton a well-defined, mappable formation or a facies of variable stratigraphic range?

In central Virginia, if the northeastern set of names is used, the Weverton has to be omitted. This might imply an unconformity, whereas, in fact, the absence of the formation is due to facies gradation.

The names Loudoun, Weverton, Harpers, and Antietam were assigned before the names Unicoi, Hampton, and Erwin. The Unicoi is approximately equivalent to the combined Loudoun and Weverton (King, 1949, pp. 522-523). Where the Weverton is not differentiated, Unicoi should be the preferred name for the formation. Thus, the Unicoi is identified at least as far as Tye River Gap, 64 miles northeast of Roanoke. Northeast from Tye River Gap for 25 miles or more there are several overthrust faults in Chilhowee rocks (fig. 2). These rocks are mylonitized and the stratigraphic section is fragmentary so that the formations are incomplete and hardly differentiable. It has not been possible in this portion of the Blue Ridge to trace the Unicoi northeastward into well-defined Loudoun and Weverton.

The Hampton formation is similar in lithology, thickness, and stratigraphy to the Harpers formation. These formations appear to be equivalent and the dual classification seems unnecessary. The name Harpers is older than the name Hampton and should have precedence. Similarly, the earlier-named

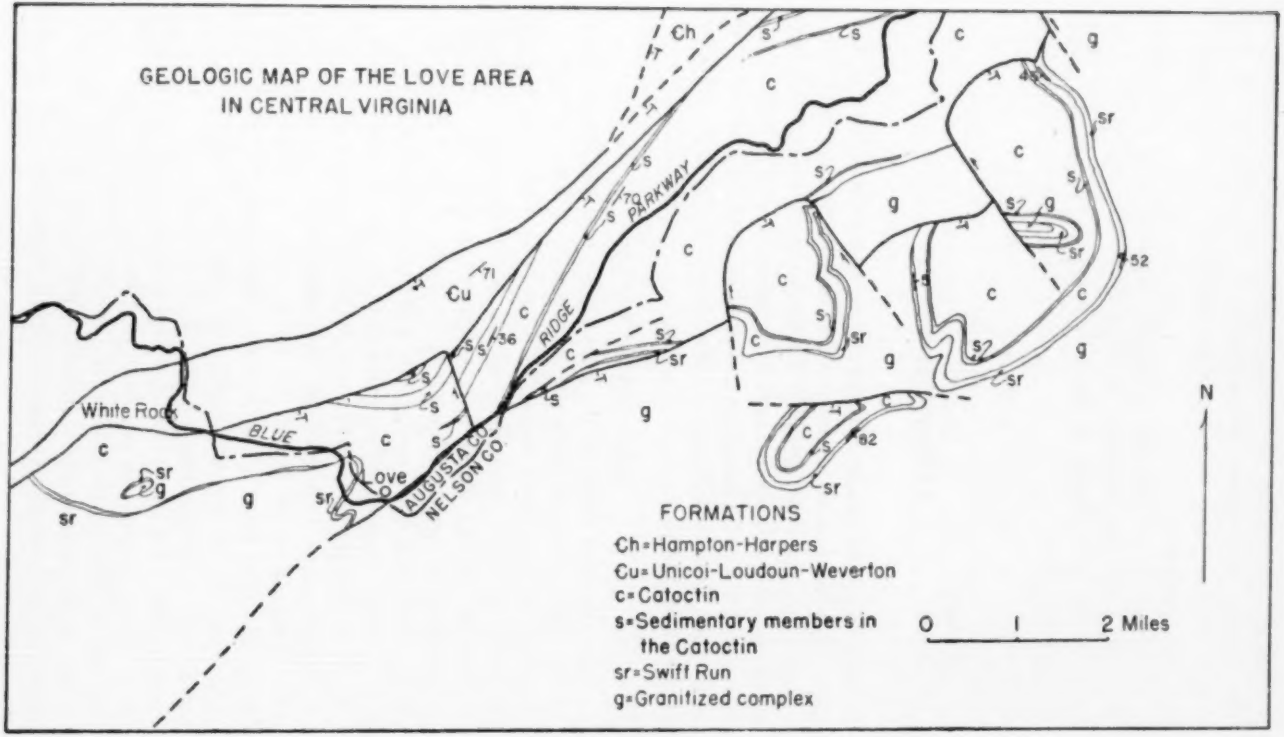

GEOLOGIC MAP OF THE LOVE AREA
IN CENTRAL VIRGINIA
Ch
Cu
c
s
sr
g
s2
BLUE RIDGE PARKWAY
White Rock
Love
AUGUSTA CO.
NELSON CO.
N
FORMATIONS
Ch=Hampton-Harpers
Cu=Unicoi-Loudoun-Weverton
c=Catoctin
s=Sedimentary members in the Catoctin
sr=Swift Run
g=Granitized complex
0 1 2 Miles

FIGURE 2

Antietam is equivalent to the Erwin and should have precedence. The Shady and Rome formations, on the other hand, were named before their northeastern equivalents, the Tomstown and Waynesboro.

On the basis of priority of names, approximate equivalence, and lithology, the sequence of formations in the Lower Cambrian of the Blue Ridge at least as far northeast as Tye River Gap should be :

Rome	
Shady	
Antietam	Chilhowee group
Harpers	Chilhowee group
Unicoi	Chilhowee group

This usage of names is contrary to convention. On the other hand, the Roanoke boundary seems to be arbitrary and unrecognizable in the stratigraphy. Perhaps the use of certain names from two well-established sets is objectionable. For this reason, the names Unicoi, Hampton, and Erwin, contrary to rule, have been used in central Virginia (Bloomer and Bloomer, 1947, pp. 96-97, 103-106).

GRANITIZED COMPLEX

The stratified rocks of the Blue Ridge and northwest margin of the Piedmont provinces unconformably overlie a complex of gneisses and granitoid rocks. This complex, in central Virginia, is 10 to 20 miles wide between the Lynchburg gneiss on the southeast and the Swift Run (Oronoco), Catoctin, or Unicoi formations on the northwest. It consists of three widespread facies including the Lovingston gneiss, Marshall granite, and hypersthene granodiorite delineated on the Geologic Map of Virginia (Virginia Geol. Survey, 1928). The Lovingston gneiss comprises about two-thirds of the complex. It forms an irregular, elongate mass about 12 miles wide at Rockfish River and 150 miles long from Roanoke River on the southwest to Thornton River on the northeast (fig.1). Marshall granite forms an irregular mass about 2 to 5 miles wide along the northwestern margin of the Lovingston. Hypersthene granodiorite forms a mass as much as 8 miles wide northwest of the Marshall. The granodiorite is unconformly overlain by the Swift Run (Oronoco), Catoctin, or Unicoi formation in the Blue Ridge. Numerous comparatively small bodies of granodi-

orite are included within the Lovingston gneiss. Marshall granite underlies low hilly country between the Blue Ridge and a belt of outlying, intricately dissected ridges formed from the Lovingston.

The hypersthene granodiorite is a medium- to coarse-grained, locally porphyritic, granitoid rock. The rock is predominantly massive, but a relic foliation formed by chlorite appears in places. There is insufficient concentration of the micaceous mineral to produce well-defined folia. Potash feldspar, plagioclase, blue and smoky quartz, and chlorite are the most persistent essential and varietal constituents. Hypersthene occurs in place of chlorite or more abundantly in scattered masses enclosed within the chlorite facies. It does not characterize the whole mass.

Marshall granite is a migmatitic-looking gray rock composed of fine- to medium-grained bands of chloritized biotite gneiss and leucocratic granite. The granite bands are generally only a few millimeters wide, but frequently occur in lenses several feet wide. Quartz veins are numerous.

Lovingston gneiss consists of a medium-grained, dark-gray, porphyroblastic gneiss and granite. It contains potash feldspar, plagioclase, blue and smoky quartz, and biotite. In the gneiss, feldspar with more or less included quartz forms augen-like and irregular masses up to an inch or more in diameter. Biotite in the Lovingston granite occurs in clusters about equal in size and quantity to the felsic portion of the rock. Small lenses and oval masses of leucocratic granite like that in the Marshall occur all through the Lovingston.

A study of the petrology of the granitized complex now in progress has led to the conclusion that the Lovingston, Marshall, and hypersthene granodiorite are intergradational and represent stages of granitization. The parent rock is a metasedimentary biotite gneiss and schist. This rock is "early" pre-Cambrian in age.

Numerous pebbles and some cobbles of rock from the granitized complex form conglomerates at the base of the Lynchburg as well as in the Swift Run (Oronoco), Catoctin, and Unicoi formations.

RELATIVE AGES IN THE GRANITIZED COMPLEX

The age of metamorphic rocks customarily depends upon the age of the unmetamorphosed equivalents and not upon the

age of the metamorphism. The age of magmatic rocks depends upon the age of emplacement or crystallization. Rocks formed by replacement are metamorphic and the age should depend upon the age of the unmetamorphosed parent rock. Some geologists now believe that all granitic rocks are formed by a process that is metamorphic in character (Perrin and Roubault, 1949). If granitic rocks are found to be formed by replacement, age relations established on the basis of a magmatic origin in the complexes that contain them need revision. In general, the age-relations problem is simplified. The Lovingston, Marshall, and hypersthene granodiorite are, for example, facies of equivalent age formed from a pre-Cambrian sedimentary complex. The sedimentary rocks were metamorphosed to gneiss and schist. Granitization may have developed during a second stage of metamorphism or it may be an end-product of more or less continuous metamorphism. If the schist and gneiss, on the one hand, and the granitized rocks, on the other, are the results of the same interval of metamorphism, they represent different grades or facies with the original sediment at one extreme and granite at the other.

Skialiths (inclusions) of the metasediment occur in bands from a few feet to almost a mile long and from a few inches to more than 100 feet wide in the granitized complex. These enclaves all have foliation parallel to the foliation of the host rock. Some of them are very similar in appearance to the Lynchburg gneiss, but almost all of them are to some extent granitized.

LYNCHBURG GNEISS

The Lynchburg gneiss was named by Jonas (1927, pp. 844-845) from exposures at Lynchburg in central Virginia. It is exposed in a belt (Geologic Map of Virginia, 1928) that extends from northern Virginia into North Carolina along the northwestern margin of the Piedmont province. Southwest of Lynchburg, where the granitized complex disappears, the Lynchburg formation has an outcrop width of almost 20 miles.

Plate 1

Figure 1. Rockfish conglomerate at the base of the Lynchburg formation near Rockfish, Virginia.

Figure 2. Cross-bedding in the Lynchburg formation near Rockfish, Virginia.

Figure 3. Phyllite in the Lynchburg formation.

PLATE 1

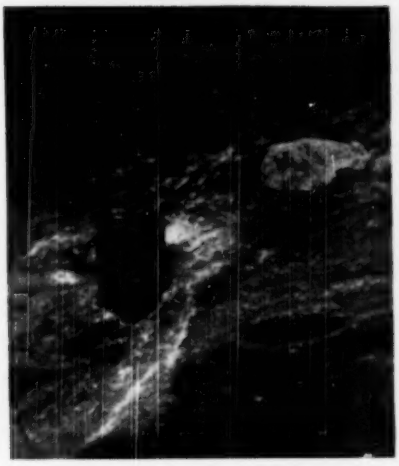


FIGURE 1

FIGURE 2

FIGURE 3

PLATE 2

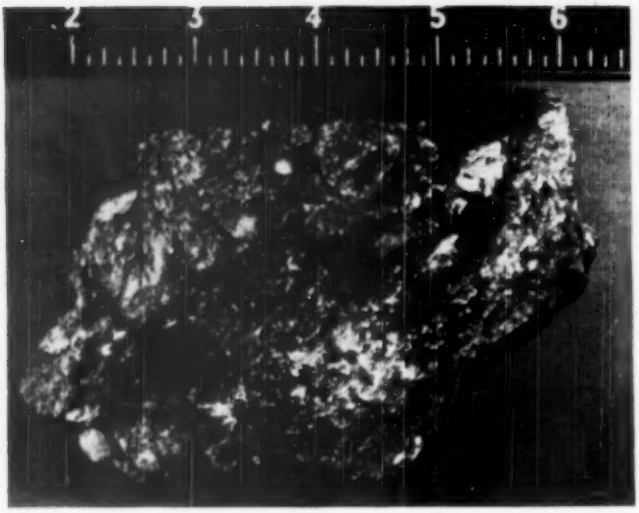


FIGURE 1

FIGURE 2

Northeast of Lynchburg the outcrop belt is only about 5 miles or less wide.

From Rockfish River northeastward, the Lynchburg is bordered on the southeast by the Catoctin and on the northwest by the Lovingston gneiss of the granitized complex. In its northeastern extension, the Lynchburg is shown on the Geologic Map of Virginia interfingering with the Loudoun formation.

Lithology.—The Lynchburg in central Virginia consists of well-sorted, stratified, and interbedded conglomerates, sandstones, and siltstones that have undergone varying degrees of metamorphism (plate 1, fig. 1). In the vicinity of Rockfish, on Rockfish River, the base of the formation is characterized by a boulder conglomerate. This conglomerate, named Rockfish conglomerate by Nelson (1932), consists of about 1000 feet of boulders, cobbles, and large pebbles contained in a matrix of metamorphosed coarse-grained, arkosic sandstone (plate 1, fig. 2). This conglomerate grades upwards into the main mass of the Lynchburg with a gradual decrease in the size of the phenoclasts. Downward, the conglomerate grades into the granitized complex through from 10 to 100 or more feet of ancient regolith. This former regolith can be distinguished with difficulty from the underlying granitic rock by the appearance of some vestige of stratification, rounded phenoclasts, a change in the lithologic structure, or a change in mineral proportions. Phenoclasts gradually increase in number and size and stratification becomes more pronounced upwards through the ancient regolith into the conglomerate. The lithic and mineral phenoclasts were derived from the underlying granitized complex. The lithic phenoclasts have precisely the same petrography as certain facies in the granitized complex. They are granitic in character. None of the gneissose or schistose facies of the granitized complex occur for certain in the conglomerate. These facies are decomposed by weathering and are not represented by fragments in the present weathered mantle over the granitized complex. The granitic facies, on the other hand, is abundantly represented in the float. In fact, the

Plate 2

Figure 1. Graywacke conglomerate in a sedimentary member in the Catoctin formation in central Virginia.

Figure 2. Sedimentary member in the Catoctin formation at Rockfish Gap in central Virginia.

profusion of granitoid float is misleading. It might easily give an entirely erroneous impression of the character of the bedrock which is predominantly gneissic beneath a mantle of predominantly granite boulders in a clay matrix. The gneissose rock weathers to clay with more or less sand depending upon the quartz content of the bedrock.

Northeast and southwest of Rockfish River, along the strike, the basal boulder conglomerate disappears at the end of a mile or two except for lenticular bodies seen from place to place. Where the Rockfish conglomerate is well represented in the section, there is, in the adjacent granitized complex, the most extensive development of granitic rock. Such a relationship is due to the resistance of the granitic facies to weathering compared to the micaceous facies.

The Rockfish in the type locality resembles a fanglomerate. The relief, however, was not great at the place and time of deposition. Otherwise the comparatively thick residual regolith at the base of the conglomerate could not have accumulated. The phenoclasts, furthermore, probably owe most of their sphericity to spheroidal weathering and not to corrasion.

Above the Rockfish conglomerate, the Lynchburg consists of thick-bedded, arkosic, pebble conglomerate and gravelly sandstone interbedded with thin-bedded, fine-grained, arkosic sandstone and siltstone. The conglomeratic beds range from less than a foot to as much as 25 feet thick. They are more numerous and thicker toward the bottom of the formation than toward the top. Pebbles are very well-rounded quartz of nearly uniform size in a given bed, but somewhat variable from bed to bed. They range from about 1 mm. to 15 mm. in size. The matrix of the conglomerate, before metamorphism, was a sandy to silty aggregate of quartz, clay, sericite, potash feldspar, and plagioclase.

The thin-bedded, fine-grained sandstone and siltstone layers, intercalated with the pebble beds, range from a few inches to a hundred or more feet thick (plate 1, fig. 3). The finer-grained facies consisted of quartz and sericite with only minor amounts of feldspar before metamorphism. Microscopic grains of biotite are concentrated in streaks and bands. Some of the black banded metasiltstone contains graphite (Stose and Stose, 1949, p. 310).

The Lynchburg is predominantly in the biotite stage of

metamorphism. In the Rockfish conglomerate, especially, but also somewhat higher in the formation, granoblasts of potash feldspar and quartz are conspicuous. These granoblasts are formed from detrital minerals and not from introduced solutions. They are believed to be a product of the regional or dynamothermal metamorphism.

The Rockfish conglomerate is a quartz, potash-feldspar, oligoclase gneiss. The folia inclose large phenoclasts which have been only slightly deformed by metamorphism. Potash feldspar porphyroblasts are abundant. Some are ovoid in shape with the long axis parallel to the foliation. Many porphyroblasts are very irregular in shape and have boundaries that cut across the folia.

Above the conglomeratic gneiss at the base, the Lynchburg consists of interbedded biotite and sericite phyllite, fine-grained schists, and medium-grained biotite gneiss.

In places, there are beds in the Lynchburg that are only inconspicuously metamorphosed. These beds are sandstones composed of more or less well-rounded quartz grains.

No limestone or dolomite or their metamorphic equivalents have been found in the Lynchburg in central Virginia.

Thickness.—The bedding and foliation throughout the Lynchburg are approximately parallel. A persistent southeast dip ranges between about 70° and 90°. The formation is some 4.5 miles wide across the outcrop in the Rockfish River section and appears to be about 20,000 to 22,000 feet thick. No conspicuous isoclinal folding is recognized. The massive pebbly and gravelly beds are not flexed so that they can be traced around the troughs or crests of isoclines or other folds. However, the intervening phyllites have folia parallel to the contact with the massive beds, but very much contorted bedding. The massive beds are not continuous, but terminate abruptly or by gradual thinning and gradation into the phyllites. Where the massive beds are abruptly terminated they may have been broken by flexure, but the tapered and sometimes bifurcated terminations were formed by facies gradation. The massive beds, consequently, are contained as lenses or large tabular masses in the siltstone and argillaceous sandstone now represented by phyllite and schist. When the Lynchburg was folded, the fine-grained rock probably "flowed" around the lenses of massive rock which rotated until they

were oriented normal to the regional stress. Where a massive lens lay across the axial plane of a developing fold, it broke to form huge boudinage-like masses that eventually occupied the limbs of the finished fold. The fine-grained, relatively incompetent rock was thinned by flowage between the massive lenses and thickened in the crest and trough zones.

Through some such process the Lynchburg might be actually isoclinally folded without the structure being readily apparent. Its thickness may then be very much less than 20,000 feet.

Stratigraphic relations.—The Lynchburg formation northeast of Lynchburg, Virginia, unconformably overlies the granitized complex and concordantly underlies the Catoctin greenstone. The lava from which the greenstone was formed was evidently extruded upon the nearly horizontal surface of the Lynchburg sediments before they were subjected to orogenic deformation and metamorphism. East of Lynchburg, Virginia, the Catoctin disappears and the Lynchburg is in contact with the Wissahickon formation. On the Geologic Map of Virginia (Virginia Geol. Survey, 1928), this contact is delineated as a fault. Northeast of Lynchburg, this fault is drawn between the Catoctin and Wissahickon. Jonas (1929, pp. 507-509) believes that the fault is indicated by a belt of diaphthorite. In central Virginia, the rocks designated as diaphthorite appear to be phyllites that have not undergone retrogressive metamorphism (diaphthoresis). A well-exposed section crossed by Rockfish River has been studied and found to contain beds of sandstone only about 5 mm. thick in the phyllites. Had these rocks been mylonitized and retrogressively metamorphosed, such delicate features as these layers of sandstone could not have survived.

There may be faults from place to place near or along the southeastern contact of the Lynchburg, but they are probably of comparatively limited extent. In fact, in the foliated rocks of the Piedmont, the identification of faults, in general, is very difficult because of the similarity of the rocks and the sparsity of reference beds or formations.

Perhaps thrust faults do not form in broad expanses of foliated rocks orogenically deformed only once. The displacement concentrated along a thrust fault in comparatively massive, competent rocks might be dissipated over a wide zone in foliated rocks by comparatively infinitesimal movements along a succession of folia. The foliated rocks, in other words, might be

the root zone of thrust faults. Such a relationship is indicated along some thrust faults in the Blue Ridge. Here well-defined faults can be traced into zones of mylonitization which in turn grade into regionally foliated rocks where the fault is lost.

Until more convincing evidence of a fault contact between the Lynchburg or Catoctin and the Wissahickon is found, the Lynchburg or Catoctin may be presumed to underlie the Wissahickon concordantly. An unconformity may be indicated by the disappearance of the Catoctin near Lynchburg. On the other hand, inasmuch as the Catoctin is an effusive, the flows may have, in places, interrupted sedimentation which was elsewhere uninterrupted. This seems to account for the disappearance of the Catoctin more satisfactorily than erosion because there is no evidence of conglomerates composed of greenstone fragments in the critical zone.

The relationship of the Lynchburg, as shown on the Geologic Map of Virginia (Virginia Geol. Survey, 1928), indicates two separate and distinct formations. In the vicinity of Rockfish River, the Lynchburg formation obviously unconformably overlies the granitized complex. West of Lynchburg, Virginia, and in the vicinity of Bedford, Virginia, the Lynchburg formation, as shown on the Geologic Map of Virginia, grades into the Lovingston facies of the granitized complex. This gradation is expressed by a gradual increase in the size and number of feldspar and quartz porphyroblasts toward the Lovingston. Throughout the Lovingston, enclaves of the metasediment are numerous. These relations indicate granitization (feldspathization).

The same formation could not unconformably overlie a granite complex in one place and grade into it in another. The Lynchburg in the type locality and northeast of Lynchburg, Virginia, is younger than the "Lynchburg" west of Lynchburg. The two formations resemble each other, but the older formation locally appears migmatitic. In this paper, the name Lynchburg refers to the younger formation. No attempt will be made to describe or propose a name for the older formation. Its relationship to the Lynchburg and other formations and its petrography need to be studied more thoroughly.

Northeast of Lynchburg, the Lynchburg formation is shown more or less intercalated with the Loudoun formation on the Geologic Map of Virginia (Virginia Geol. Survey, 1928). This

map was made when it was thought that the Lynchburg is one of the oldest rocks in Virginia and the Loudoun is Lower Cambrian in age (Jonas, 1927, pp. 844-845). It has been found that the Lynchburg and the associated so-called Loudoun intercalations are undifferentiable. Presumably, some of the only slightly metamorphosed zones in the Lynchburg were identified as a definitely distinct and younger formation. All of the rocks between the Catoctin belt on the southeast and the granitized complex on the northwest are Lynchburg. They have been studied in some detail from northeast of Charlottesville to Lynchburg and reconnoitered into northern Virginia. The stratigraphy in Loudoun County, in northern Virginia, appears to be somewhat confused. Keith (1894) mapped and named the formations in the Blue Ridge and Piedmont in Loudoun County. Evidently he chose an exposure near Aldie as the unspecified type section of the Loudoun in preference to some locality along the northwest side of the Blue Ridge. The formation in the "type" locality, however, seems to underlie the Catoctin and is thus equivalent to the Lynchburg, whereas the "Loudoun" along the northwest side of the Blue Ridge overlies the Catoctin. This presents something of a dilemma because the "Loudoun" along the northwest flanks of the Blue Ridge is younger than the "Loudoun" in the "type" locality. The formation at the base of the Chilhowee group in northern Virginia, has long been established in the literature as the Loudoun. On the other hand, it appears that the Lynchburg and Loudoun in the respective type sections are approximately equivalent. According to rule, the name Lynchburg should be abandoned and replaced by the older name Loudoun. Another name would then have to be given to the basal formation in the Chilhowee group in northern Virginia. If the Weverton is a well-defined unit, the name Unicoi could not be properly extended to include the problematical formation. However, if the Weverton is a facies of indefinite position, as in central Virginia, perhaps the name Unicoi would be appropriate. Although contrary to rule, the simplest solution might be to retain the name Loudoun as it is now used in northern Virginia, and apply the name Lynchburg to the formation beneath the Catoctin.

Nowhere does the Lynchburg cover all of the granitized complex and form a continuous section into the Blue Ridge. It is exposed in the southeast limb of the Catoctin-Blue Ridge

anticlinorium (fig. 4). In the northwestern limb of this fold, in the Blue Ridge, the Catoctin is, in places, separated from the granitized complex by a sedimentary formation from 0 to several hundred feet thick. This formation was named Oronoco by Bloomer (1947, p. 95) and Swift Run by Stose and Stose (1946, pp. 18-19).

In the granitized complex between the Oronoco-Swift Run belt on the northwest and the Lynchburg formation on the southeast, there are, in central Virginia, no known major faults that interrupt the continuity of the section. It is thus reasonably certain that the Oronoco-Swift Run formation is the thinned western edge of the Lynchburg. This relationship is also indicated by the occurrence of Catoctin greenstone above the Lynchburg on the southwest and above the Oronoco-Swift

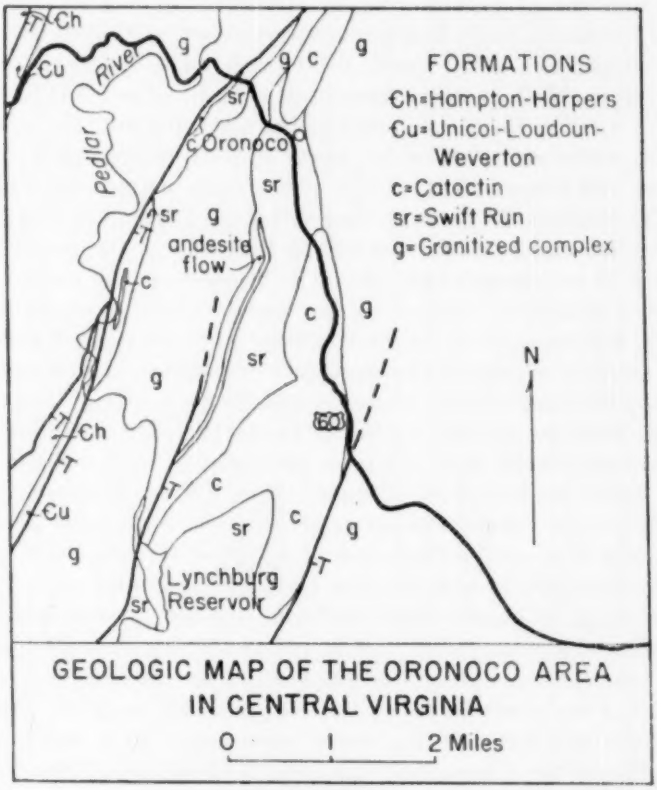


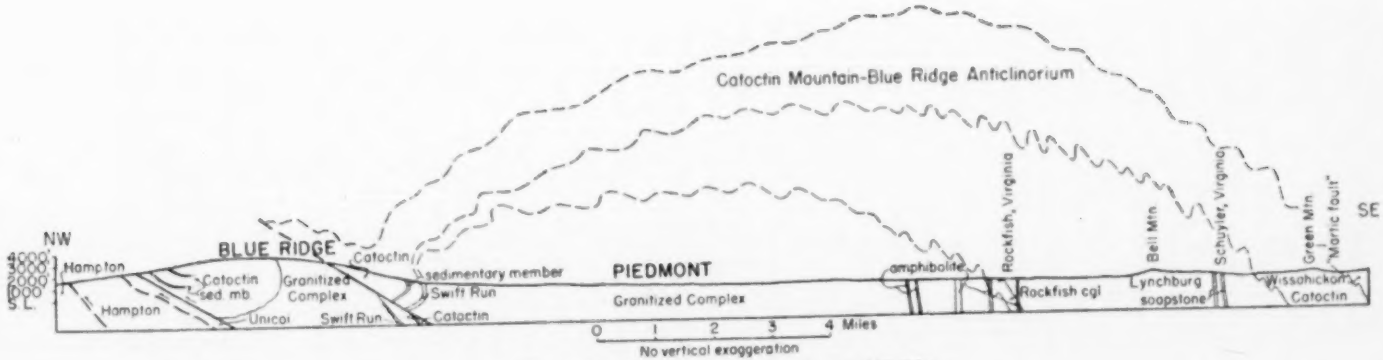
FIGURE 3

Run on the northwest. The Catoctin is presumed to be a once unbroken tabular body of lava flows now exposed in two belts in the opposite limbs of a large anticlinal fold.

The Lynchburg, thus, overlaps the granitized complex from east to west and attains its full thickness in a vast basin of deposition east of the Blue Ridge. The basal conglomerate of the Lynchburg and sediments in the Oronoco-Swift Run and Catoctin formations derived from the granitized complex and the overlap relations clearly indicate the transportation of sediment from west to east.

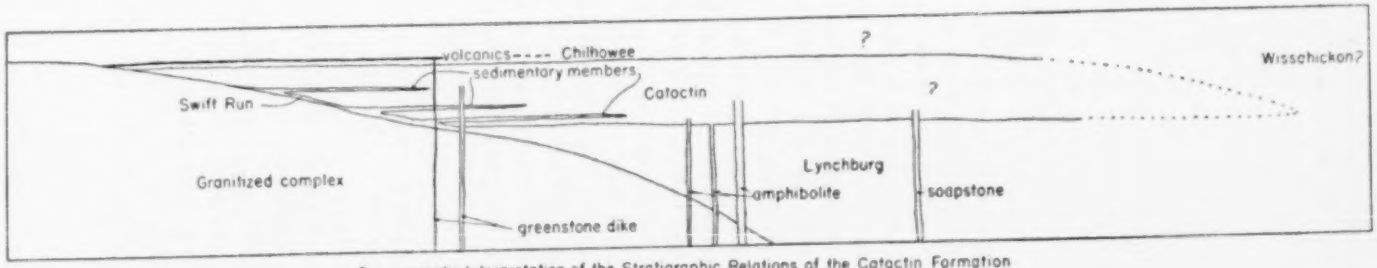
SWIFT RUN (ORONOCO) FORMATION

Stose and Stose (1946, pp. 18-19) identified about 50 feet of arkosic sandstone, conglomerate, and tuff between the Catoctin and the granitized complex (granodiorite). They named this formation Swift Run for exposures near Swift Run Gap in Rockingham County near Elkton, Virginia. Bloomer and Bloomer (1947, p. 95) subsequently used the name Oronoco for a similar formation between the Catoctin and the granitized complex, in Amherst County near Oronoco Post Office. Stose and Stose (1949, p. 311), in a later paper, claim that the Oronoco is the same as the Swift Run. They state that the formation can be traced from Swift Run Gap to Oronoco Post Office. It is probable that the name Oronoco is not valid and that it should be replaced by the name Swift Run or Lynchburg. However, about a mile northeast of Oronoco Post Office, the Oronoco disappears by overlap from beneath the Catoctin. This particular mass of Catoctin and the underlying Oronoco-Swift Run are isolated by thrust faults (fig. 3). No Catoctin or Oronoco-Swift Run is known southwest of James River, a few miles southwest of Oronoco Post Office. Northeast of Oronoco, the Catoctin is not exposed in the section for about 15 miles. The southwestern end of a belt of Catoctin that extends along the Blue Ridge into Maryland is located near Tye River Gap. In places, the Catoctin in this belt is underlain by a sedimentary formation and in places it rests directly upon the granitized complex. Also the base of the Catoctin is overthrust, from place to place, by the granitized complex. Some of these fault contacts are several miles long. One is easily accessible on the Chesapeake and Ohio Railway at Afton, Virginia. Faults and overlap, consequently, prevent tracing the



Section approximately along Rockfish River in central Virginia

FIGURE 4



Diagrammatic Interpretation of the Stratigraphic Relations of the Catoctin Formation

FIGURE 5

Oronoco into the type section of the Swift Run, about 70 miles to the northeast. There are, furthermore, in the Catoctin a number of sedimentary members from a few to nearly 1,000 feet thick. Most of these sedimentary members are composed of rocks very similar to those in the Oronoco or Swift Run. Because the Catoctin evidently overlaps the granitized complex from east to west, any one of a succession of sedimentary members might from place to place underlie the greenstone.

Furcron (1939, pp. 37-41) identified an undisclosed thickness of metasedimentary rocks beneath the Catoctin in Fauquier County in northern Virginia which he named the Fauquier formation. He believes the Fauquier may be equivalent to the Lynchburg.

In the Rockfish River section of the Blue Ridge, the sedimentary formation between the Catoctin and granitized complex is probably the thin margin of the Lynchburg overlap. The Oronoco and Swift Run are, consequently, equivalent to some part of the Lynchburg or Catoctin depending upon the gradient of the pre-Lynchburg erosion surface and the distance up this slope (fig. 5). The Lynchburg was named before any of the formations in question except the Catoctin. However, because they are only locally and partly equivalent and the lithology is very noticeably different, perhaps the extension of the name Lynchburg to include the rocks now differentiated as Swift Run or Oronoco would be incorrect. Furthermore, the name Oronoco should be abandoned in favor of Swift Run with the understanding that the vertical position thickness and lithology of the formation may vary from place to place. Relative to the granitized complex, the Swift Run occupies about the same position as the Rockfish conglomerate, an earlier-named unit. Some geologists, consequently, may favor the name Rockfish in place of the name Swift Run. The Rockfish is overlain by the Lynchburg of which it is a facies, whereas the Swift Run is overlain by the Catoctin. It thus may be preferable to restrict the Rockfish to the Piedmont and retain the name Swift Run.

Lithology.—The Swift Run in central Virginia consists of from 0 to more than 400 feet of graywacke and arkosic conglomerate and sandstone, tuff, and thin greenstone and andesitic effusives of limited extent. One of the best sections is exposed along U. S. Route 60 east of Oronoco Post Office (fig.

3). About one mile southwest of this section, an andesite of volcanic origin is present near the middle of the Swift Run. Other good but comparatively inaccessible sections are located near the head of Rockfish River in Nelson County.

The lithology of the Swift Run varies from place to place. It grades downward into the underlying granitized complex through 10 to more than 50 feet of ancient regolith. In steep or overturned limbs of folds, the ancient regolith is represented by sericitic phyllite. Where dips are gentle there is little metamorphism.

The ancient regolith grades upwards into a conglomerate composed locally of boulders and cobbles and extensively of pebbles of granite, quartz, and feldspar in a micaceous matrix. This conglomerate grades upwards into a coarse- to medium-grained, greenish-gray graywacke. In a few sections, near the top, the Swift Run contains a 20-foot bed of cross-bedded sandstone composed of clear quartz grains with a matrix of introduced epidote. The quartz grains are uniform in size, well rounded, and frosted.

From east to west, the Swift Run converges until it disappears from beneath the Catoctin greenstone. The regolith extends to the margin of the overlap and beyond, but is not everywhere recognized between the Catoctin and granitized complex. In other words, the Catoctin, in a few places, appears to rest upon comparatively undecomposed and undisintegrated granite.

Localized greenstone flows in the Swift Run, not more than about 20 feet thick, are petrographically indistinguishable from the Catoctin greenstone and greenstone flows in the lower part of the Unicoi. Near Oronoco, the flow in the Swift Run has not been altered to greenstone and its original petrographic character is easily discernible. It is an ophitic andesite composed essentially of andesine and minor amounts of biotite, quartz, and potash feldspar.

CATOCTIN FORMATION

The Catoctin was named by Geiger and Keith (1891, plate IV) from exposures in Catoctin Mountain near the northeastern end of the Blue Ridge province. It is exposed in two parallel belts that extend into central Virginia. One belt caps the main mass of the Blue Ridge and the other belt occurs in an alignment of ridges about 20 miles to the southeast. In cen-

tral Virginia, the northwestern belt of the Catoctin is thrust upon the Chilhowee group, but farther northeast it underlies the Loudoun. In some places, the Catoctin in the northwestern belt overlies the Swift Run or granitized complex. Elsewhere, the granitized complex has been thrust upon the Catoctin and the base is unexposed. The southeastern belt, southeast of the Blue Ridge, is part of the southeastern limb of the Catoctin Mountain-Blue Ridge anticlinorium. Therefore, the Catoctin in central Virginia is exposed in both limbs of a major anticlinal fold. This fold has been truncated by erosion to a depth equivalent, at least, to the combined thickness of the Catoctin and Lynchburg formations. Along the northwestern limb of this fold near the Catoctin belt there are a few outliers of the Catoctin underlain by Swift Run. No other outliers of the Catoctin or underlying metasedimentary rocks are known with the possible exception of slate in a body about one-half mile wide and 6 miles long at Mechum River midway between Rockfish Gap and Charlottesville. This body is located near the axial zone of the Catoctin Mountain-Blue Ridge anticlinorium. Little is known of this slate. It is metasedimentary and may be a down-faulted mass equivalent to some part of the Lynchburg.

Lithology.—The Catoctin formation consists of about 5000 feet of greenstone with widely separated, discontinuous sedimentary members. These sedimentary members range from a few inches to as much as 750 feet thick (plate 2). Owing to secondary alteration, it is difficult to ascertain the original composition of the greenstone. Although no unaltered specimens have been found, some are more altered than others. The primary texture is clearly ophitic and fine-grained with scanty phenocrysts. Amygdules, veins, pods, and small irregular masses of milky quartz; milky quartz and epidote; or milky quartz, epidote, and potash feldspar occur irregularly throughout the formation. In the northwestern belt, the Catoctin is massive except locally along some faults. The Catoctin in the southeastern belt (in the Piedmont), on the other hand, is a green schist or phyllite.

Andesine, as remnants and "ghosts", is the only certainly identified primary mineral. It comprises at least 50 per cent of the primary composition.

The interstices among laths of feldspar are occupied by ag-

gregates of secondary minerals in which tiny remnants of biotite and a pyroxene (augite?) have been noted. These minerals are presumably relics of the primary mafic minerals. In only a few among many specimens studied, small grains of quartz and potash feldspar have been identified. Some of these grains may be primary.

Secondary minerals obscure or obliterate the primary minerals and primary texture of the greenstone. These secondary minerals include an abundance of epidote and chlorite and variable amounts of sericite, tremolite, actinolite, clinozoisite, quartz, potash feldspar, hematite, ilmenite, and leucoxene.

The primary composition of the Catoctin is so obscured by secondary minerals that classification is difficult. Keith (1894, pp. 302-309) recognized altered basalts, andesites, and rhyolites in northern Virginia. More recent writers generally refer to the greenstone as a metabasalt. In central Virginia, indirect evidence seems to indicate andesite (Bloomer and Bloomer, 1947, pp. 99-100).

No rhyolite has been found in central Virginia. Layers of red slate in the greenstone and in sedimentary members of the greenstone resemble rhyolite, but are probably metamorphosed tuffs.

The altered Catoctin is widely known as greenstone. The writer (Bloomer and Bloomer, 1947, p. 100) is responsible for classifying these effusives as propylite. He thought the term greenstone too generalized. However, there is probably no important objection to the term "greenstone".

In some ways, the Catoctin resembles spilite. No pillow structure, common in spilite, has been identified nor is it known for certain whether or not the Catoctin was extruded subaqueously. However, it does seem to be part of a geosyncline and its composition approximates spilite.

In the Love area (fig. 2) of the Blue Ridge, several sedimentary members have been mapped in the Catoctin. These members consist of from 0 to as much as 750 feet of graywacke pebble conglomerates and sandstones, epidotized quartz sandstones, and thin beds of red tuff. The pebbles are predominantly quartz, but some are granite and feldspar. No greenstone or Lynchburg gneiss pebbles have been found.

Locally the conglomerate consists of angular pebbles of feldspar and quartz in a micaceous matrix and resembles

granite. A careful search or traverse along the strike reveals well-rounded and frosted pebbles, stratification, and facies gradation.

Stratigraphic relations.—The Catoctin overlaps the Lynchburg, Swift Run, and granitized complex from east to west (figs. 2, 3, 4, 5). In northern Virginia, the Catoctin is overlain by the Chilhowee group. In central Virginia, it is thrust-faulted upon the Chilhowee group so that the stratigraphic relationship is unexposed and must be extrapolated. Near Tye River Gap, the Chilhowee group rests unconformably upon the granitized complex. Consequently, the Catoctin must disappear from beneath the Chilhowee. Although the disappearance may be attributed to erosion, the major cause is probably due to overlap or convergence. This conclusion is supported by several indirect lines of evidence as follows:

1. Conglomerates at the base of the Chilhowee group contain no pebbles of greenstone, but an abundance of granitic detritus. How could the sediments in the base of the Chilhowee have been transported from east to west more than 20 miles across an eroded surface of Catoctin and be devoid of greenstone (figs. 4, 5)? Furthermore, where did the granite come from? These sediments must have moved from west to east and the Chilhowee must be part of a succession of overlapping formations beginning at least with the Lynchburg.

2. The Swift Run overlaps the granitized complex from east to west. The Catoctin is concordant with this formation and must similarly overlap it and somewhere disappear beneath the Chilhowee.

3. At Love (fig. 3) about 6 miles northeast of Tye River Gap, the Catoctin is separated from the granitized complex by the Swift Run. This locality is probably near the *northwestern* margin of the Catoctin. About a mile northeast of this exposure there is a succession of several sedimentary members in the Catoctin. Unfortunately, in this locality the Catoctin lies between thrust faults. However, the proximity of the Swift Run and the sedimentary members may indicate the proximity of the northwestern margin of the Catoctin overlap. The sedimentary members contain no greenstone detritus. Furthermore, their greater thickness and frequency here, compared to the middle and southeastern margin of the Catoctin belt, suggests they are broad fans that spread and

finally disappear from west to east over greenstone (figs. 4, 5). Also, along the western margin of the greenstone, some or all of the sedimentary members may merge into the overlapping Swift Run formation. These relations indicate overlap.

4. At or within a few feet of the base of the Chilhowee, there are volcanic flows and tuffs (Furcron and Woodward, 1936). These volcanic rocks are not more than 25 feet thick and the flows are absent in many sections. The flows are, in some places, only slightly altered, but in some places they are greenstones. The tuffs are represented by red slates. These greenstones and slates are petrographically similar to the greenstones and tuffaceous slates in the older Catoctin formation (plate 3).

If the Catoctin overlaps the granitized complex from east to west, the volcanic rocks at the base of the Chilhowee may represent the thin, western margin of the overlap. In other words, the Chilhowee volcanics represent the last of a series of eruptions now largely represented by the Catoctin.

CHILHOWEE GROUP

Little need be said here about the Chilhowee group aside from a statement to remind the reader of certain relations. Although Resser (1933, pp. 743-746) proposed that the Chilhowee formations (Hampton and Unicoi) beneath the Erwin be considered pre-Cambrian (Beltian), but Paleozoic in age, most geologists agree that the whole group is Lower Cambrian in age.

In northern Virginia, the Chilhowee rests upon Catoctin greenstone, but in central and southwestern Virginia, it rests upon the granitized complex. There can be no doubt of an unconformity at the base of the Chilhowee. There is, however, a question regarding the magnitude, significance, and nature of this unconformity. Before this question can be satisfactorily answered, the attitude and relations of the Catoctin must be established. In the preceding pages, an attempt has been made to do this. The Catoctin seems to overlap successively the Lynchburg, Swift Run, and granitized complex from east to west.

There is no conspicuous evidence of an angular unconformity between the Catoctin and the Chilhowee. Along the margin of

the overlap such an unconformity might seem to appear, but the angularity in such a case would be horizontal and not vertical. In other words, it would not indicate the orogenic deformation of the Catoctin prior to the deposition of the Chilhowee. Where the Chilhowee overlies the Catoctin it is difficult to prove or disprove an angular unconformity because of the absence of well-defined flow-boundaries in the greenstone. Sedimentary members in central Virginia clearly reflect the structural attitude of the greenstone. If such members occur in the Catoctin where it is overlain by the Chilhowee, the structural relations can be ascertained. Unfortunately, in central Virginia where there are numerous sedimentary members, the Catoctin is thrust faulted upon the Chilhowee. On the other hand, in northern Virginia, where the Chilhowee overlies the Catoctin, sedimentary members seem to be scarce or absent or mistaken for other formations.

The conglomerate rocks in the basal portion of the Chilhowee contain pebbles of quartz and granite, but appear to be devoid of greenstone or tuff pebbles. Rare fragments have been found that resemble these rocks, but microscopic examination reveals them to be fine-grained graywackes colored by chlorite, sericite and siltstones with a dense matrix of hematite. Not a single specimen of indisputable greenstone or tuff has been found in the conglomerates.

If the Catoctin occurs extensively beneath the Chilhowee and the Chilhowee conglomerates were transported from east to west across several miles of Catoctin (figs. 4 5), why are the Chilhowee basal conglomerates almost, if not completely, devoid of greenstone fragments? Obviously the sediment must have come from the west and at least the basal portion of the Chilhowee must overlap the granitized complex from east to west.

Such a relationship between the Catoctin and the basal Chilhowee suggests that these formations may not be separated by an unconformity that indicates a major difference in their ages.

Another feature that seems to provide a basis for the correlation of these formations is the volcanic rocks in the base of the Chilhowee. Bloomer and Bloomer (1947, pp. 103-106) conclude that these volcanics and those in the Catoctin are petrographically similar. Stose and Stose (1949, pp. 314-315)

somehow concluded that Bloomer and Bloomer mistook the Chilhowee volcanic rocks for Catoctin and the underlying Chilhowee sedimentary rocks for Swift Run. Bloomer and Bloomer not only recognize the volcanics in question as Chilhowee, but see in them a key to the relationship of the Catoctin and the Chilhowee. Stose and Stose (1949, p. 315) also state that the volcanics in the Chilhowee do not resemble those in the Catoctin and Swift Run. It is true that in places the effusive in the Chilhowee is a black, basaltic rock unlike any rock yet found in the Catoctin. This black, basaltic rock is petrographically very similar to the effusive near the middle of the Swift Run near Aronoco (fig. 3) in Amherst County. Furthermore, the Chilhowee effusive is a greenstone in places. This greenstone may be seen on the Blue Ridge Parkway at White Rock (fig. 2) overlook about 7 miles northeast of Tye River Gap; on the north side of James River about one-half mile downstream from the Snowden bridge where U. S. Route 501 crosses James River; on Virginia Route 56 just west of Tye River Gap; and at other places. In hand specimens and thin sections, this Chilhowee greenstone is indistinguishable from Catoctin greenstone. Also, spectrochemical analyses (table 2) of these greenstones reveal the same elements. The trace elements are presumably fortuitous and would hardly be duplicated in rocks of widely different ages from different sources.

Above the basal conglomerate, the Chilhowee grades into marine deposits. In the middle and top of the group, there is

TABLE 2

Spectroanalyses of Greenstone and Basalt						
1	2	3	4	5	6	7
Al	Al	Al	Al	Al	Al	Al
Ba	Ba	Ba	Ba	Ba		
Ca	Ca	Ca	Ca	Ca	Ca	Ca
					Cr	Cr
Cu	Cu	Cu	Cu	Cu	Cu	Cu
Fe	Fe	Fe	Fe	Fe	Fe	Fe
K	K	K	K	K		
Mg	Mg	Mg	Mg	Mg	Mg	Mg
Mn	Mn	Mn	Mn	Mn		
Na	Na	Na	Na	Na	Na	Na
					Ni	
Si	Si	Si	Si	Si	Si	Si
Sr	Sr	Sr	Sr	Sr		
Ti	Ti	Ti	Ti	Ti	Ti	Ti

1. Unicoi greenstone in the James River section.
2. Unicoi greenstone at White Rock overlook on the Blue Ridgeway.
3. Catoctin greenstone northeast of Love, Virginia.
4. Catoctin greenstone in Green Mountain.
5. Amphibolite near Rockfish, Virginia.
6. Basalt in the Triassic of New Jersey.
7. Metabasalt in the pre-Cambrian of Michigan.

an abundance of siliceous sandstone (orthoquartzite) formed from pure quartz sand. The uppermost sandstone grades into Shady dolomite. These rocks are unquestionably parts of the Appalachian geosyncline in which the sediment came, at least in part, from the east. A reversal of the direction of the movement of sediment must have occurred sometime during the deposition of the Chilhowee. This raises problems that cannot be answered until more work is done. Presumably the landmass west of the Blue Ridge was peneplaned and flooded by the sea. The sediments deposited in this sea may have come from the basal Chilhowee, Catoctin, Swift Run, and Lynchburg formations that were to some degree elevated to the east. This presupposes that deposition to the east terminated, which is by no means certain. In fact, while the validity of the Martic overthrust is in doubt, there is the possibility that the Wissahickon is a metasedimentary formation deposited upon the Catoctin and Lynchburg. Such a possibility not only indicates a continuation of sedimentation to the east, but requires that the Chilhowee group and possibly younger formations are in some part equivalent to the Wissahickon. Where then were the lands that drained to the sea in which these sediments were deposited? The Wissahickon presumably formed for the most part from impure clastic sediments with only minor amounts of interbedded limestones. Above the Chilhowee the formations contain much limestone and dolomite. This suggests the facies became more clastic and probably more heterogeneous from west to east. Does this mean that somewhere far to the east there was a landmass and that the surface which the Lynchburg, Swift Run, Catoctin, and lowermost Chilhowee overlap was the low-lying western margin of a basin which spread westward? The Appalachian geosyncline from the Blue Ridge westward would then be the foreland marginal portion of a large geosyncline to the east. This large geosyncline occupies part of the region presumed to have been occupied by the old land of Appalachia. The extension of the Appalachian geosyncline to the east somewhat restricts the western extent of Appalachia. Perhaps this old land retreated eastward as the geosyncline spread eastward and westward.

ALTERED BASIC DIKES

There are many amphibolite, soapstone, and greenstone dikes in the region between the Catoctin formation in the Blue

Ridge and the Catoctin formation in the Piedmont. These dikes are from a few inches to several hundred feet wide and up to several miles long. There is a swarm of them along the boundary between the Lynchburg and the granitized complex (fig. 4). Here, the dikes are not only more numerous, but larger. Although there are exceptions, the greenstone dikes are found in the granitized complex, amphibolite dikes in both the Lynchburg and granitized complex near the contact, and soapstone dikes in the Lynchburg east of the amphibolite dikes. These dikes probably are all genetically related. In some of them, amphibolite grades into soapstone or greenstone. Rarely, greenstone forms a thin zone along the walls of the amphibolite dikes.

All the rock types in the dikes weather comparatively rapidly. They are often represented by a yellowish-brown, plastic clay. Fresh exposures are scarce.

All the dikes parallel are nearly parallel the strike of the foliation and stratification of the intruded rocks.

The amphibolites, soapstones, and greenstones contain such an abundance of secondary minerals that both the primary minerals and textures have been largely obliterated (plate 4). In some of the greenstones, remnants of feldspars (andesine, Ab_7An_3) and an ophitic texture are apparent. Presumably, the amphibolite and soapstone were formed from a gabbroic rock or the coarse-grained equivalent of the greenstone. This is little more than a guess based upon uncertain relics of minerals and texture and the assemblage of secondary minerals which probably came from a mafelsic rock. These secondary minerals are similar to those in the greenstone and include hornblende, quartz, chlorite, epidote, clinozoisite, sericite, serpentine, calcite, talc, hematite, ilmenite, leucoxene, and probably others. The order of abundance varies. In the amphibolites, hornblende is generally most abundant; in the greenstone, epidote and chlorite; and in the soapstone, talc. There are gradational facies between amphibolite and soapstone in which talc and hornblende (actinolite) are nearly equally abundant.

Spectroanalyses of these dike rocks yield an assemblage of trace elements very similar to those in the Catoctin (table 2). This, the petrographic similarity of the greenstone in dikes to that in the Catoctin, and the location of the dikes suggests that the dikes are the hypabyssal phase of Catoctin volcanism (Furcron, 1939, pp. 26-28).

A comparatively large number and persistence of dikes along the contact zone between the Lynchburg and granitized complex encourage postulation. This zone is located about midway between the northwestern and southeastern Catoctin belts (fig. 4). If the Swift Run is the thin margin of the Lynchburg overlap, the Lynchburg thickens very rapidly. The formation has an apparent thickness of more than 20,000 feet. A true thickness of this magnitude would require an increase of thickness of about 1000 feet per mile from west to east. It is probable, however, that the true thickness of the Lynchburg is something less than 20,000 feet and that the apparent thickness is due at least in part to isoclinal folding and large-scale boudinage structure. In any case, the Lynchburg must be a comparatively thick formation of shallow water sediments. These sediments probably accumulated with synchronous subsidence. Northwest of the Lynchburg, subsidence must have gradually decreased as shown by the thinning and disappearance of the Swift Run. When the Lynchburg had attained a certain thickness, perhaps a hinge zone in the subsiding region had become sufficiently strained to fracture. Magma may have intruded along these fractures and flowed out upon the surface to form the Catoctin. In central Virginia, no dikes have been recognized in the Catoctin. This apparent absence of dikes suggests the Catoctin masses now represented in the section are portions of flows somewhat distant from the main source of the lava.

AGE RELATIONS

Stose and Stose (1949, p. 315) and King (1949, pp. 536-538) are of the opinion that the Catoctin, Swift Run, and Lynchburg are late pre-Cambrian in age. This opinion seems to depend upon an unconformity at the base of the Lower Cambrian Chilhowee group. The fact that the Lynchburg, Swift Run, and Catoctin are, in general, somewhat more meta-

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Plate 3

Photomicrographs

Figure 1. Andesite near the middle of the Swift Run formation near Oronoco, Virginia. The feldspars are andesine. Crossed nicols, 62x.

Figure 2. Greenstone from the Catoctin formation near the head of Rockfish River. The feldspars are andesine. Crossed nicols, 62x.

Figure 3. Greenstone from the base of the Unicoi formation southeast of Buena Vista, Virginia. The feldspars are andesine. Crossed nicols, 62x.

PLATE 3

FIGURE 1

FIGURE 2

FIGURE 3

PLATE 4

FIGURE 1

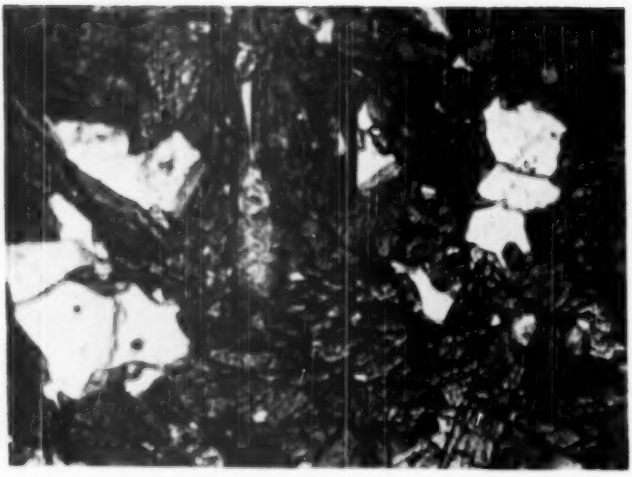

FIGURE 2

morphosed and more complexly folded and faulted, probably strengthens the opinion that these formations are pre-Cambrian in age and not closely related to the Chilhowee. Furthermore, it is presumed that the volcanics in the Catoctin are unrelated to those in the Unicoi.

In the Blue Ridge, the structural geology is comparatively complex. Thrust faults fragment folds so that the continuity of exposed cross sections is limited. The Catoctin in central Virginia is thrust upon the Chilhowee so that the stratigraphy is obscured. In northern Virginia, the Catoctin underlies the Chilhowee. Whether or not the boundary is a major unconformity is problematical. If the Lynchburg, Swift Run, Catoctin, and lower portion of the Chilhowee overlap the granitized complex, the unconformity may not be so significant. Furthermore, if the volcanics in the base of the Chilhowee represent the final eruptions of the volcanism that produced the Catoctin, no major lapse of time is represented by the contact. These relations suggest that sedimentation in the region began with the Lynchburg and continued at least into the Chilhowee, interrupted only by volcanism which produced tuffs and effusives in the Swift Run, Catoctin, and lower Chilhowee. During intervals of volcanic quiescence, sedimentation produced members in the Catoctin.

The Lynchburg, Swift Run, Catoctin, and Chilhowee, thus, appear to be in a sequence that is unbroken by an unconformity of more than minor significance. If this is true, the pre-Cambrian-Cambrian boundary must be (1) in the Chilhowee, (2) between the Catoctin and Swift Run or Lynchburg, (3) at the base of the Lynchburg, or (4) between the Chilhowee and Catoctin. The oldest positively Cambrian fossils are found near the top of the Erwin (Antietam) formation. This formation is then incontrovertibly Lower Cambrian in age. It grades downward into the Hampton (Harpers) formation and is part of the Chilhowee group. The pre-Cambrian boundary is below the Erwin. Resser (1933, pp. 743-746) proposed the recognition of the base of the Cambrian at the base of the Erwin. If the boundary is drawn on the basis of fossils, Resser's proposal seems sound. Some geologists might object to including, in the Cambrian, about 600 feet of non-fossiliferous Erwin

Plate 4

Figure 1. Amphibolite in dike near Rockfish, Virginia.
Figure 2. Photomicrograph of amphibolite near Rockfish, Virginia 100 x.

below the fossil-bearing top of the formation. Others, who base their argument upon physical relations, might object to drawing the boundary within what appears to be a more or less unbroken sequence. They prefer to utilize unconformities as time boundaries. In either case, there seems to be reason to doubt the validity of a pre-Cambrian-Cambrian boundary drawn at the base of the Chilhowee. In a given region, an interval of volcanism is presumed to be of comparatively short duration and it does not seem right to correlate such an event so that it is part Cambrian and part pre-Cambrian. There are, however, examples known to all geologists where systemic boundaries are contained within formations. Similarly the pre-Cambrian-Cambrian boundary might be located within a formation or unbroken sequence of formations.

The writer does not know whether the Lynchburg, Swift Run, Catoctin, and lower Chilhowee are Cambrian or late pre-Cambrian. Where appropriate fossils are found the rocks are Cambrian. There is always the chance that such fossils may be found in rocks lower in the section. Until some such acceptable evidence is found, the question of age hardly seems to be a matter for controversy. Most Blue Ridge geologists seem to agree that the formations between the Chilhowee and granitized complex are late pre-Cambrian in age. There is some question as to "how late" these formations are and "how low" the Lower Cambrian. The writer has attempted to prove that the problematical formations are part of a continuous sequence and, therefore, closely related in age.

ACKNOWLEDGMENTS

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Y. William Isachsen and Harry J. Werner ably assisted in the field and participated in countless discussions of the problems. The contribution of these men is inestimable. Richard Rezak and John Rodgers critically read and corrected numerous errors in the manuscript. To each of these men, the writer extends sincere thanks.

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INTENSIVE FROST ACTION ALONG LAKE SHORES

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ABSTRACT. The gravel on beaches in the Finger Lake district of New York is mostly limestone, and it is derived from the boulder clay that blankets much of the region. On most beaches the cobbles are angular to subangular, because they are being ruptured by frost action faster than the fragments can be rounded by waves. Water, to feed growing ice crystals which cause rupture, can be drawn into dense-textured, limestone cobbles embedded in wet clay; for water in fine-grained soils and rocks can be undercooled in the immediate vicinity of ice crystals. Coarse-textured rock, such as sandstone, and dense-textured limestones resting on gravel are seldom broken by freezing, and, therefore, become well rounded. Since water occupying the larger voids of sandstone and gravel freezes readily, it cannot be drawn up to ice crystals growing in small voids at slightly lower temperatures.

INTRODUCTION

AT many places along lake shores in the Finger Lake district of New York environmental conditions are extremely favorable for fragmentation of boulders and cobbles by frost action. At other localities along the shores conditions are not so favorable. During a period of many years the writer has made observations at various localities on Seneca, Cayuga, Owasco, Skaneateles and smaller lakes in the district but the most detailed work has been done on the shores of Cayuga Lake.

From the standpoint of frost action, five types of shore line may be distinguished:

1. Beaches with a thin layer of gravel resting on clay or mud probably form the commonest type. The materials on these beaches are derived from the glacial till which blankets most of the region.

2. Beaches having a thick deposit of gravel are found chiefly where small streams flowing in post-glacial gorges reach the lakes.

3. Beaches consisting of thick deposits of sand, silt or mud with no coarse material are found mostly in protected coves and where large deltas have been built at the heads of lakes.

4. Shale beaches, consisting mainly of small fragments of shale, are found where shale crops out along the lake shores.

5. Limestone shores are found where beds of Paleozoic limestones crop out.

The distinction between the different types of beaches is not always sharply defined since there are gradations from one type to another.

BEACHES WITH A THIN LAYER OF GRAVEL ON CLAY OR MUD

Storm waves and windblown ice erode boulder clay along the lake shores with the formation of low scarps at high water level. The coarse material is being concentrated on the beaches and in shallow water, the clay being gradually moved into deeper water. Lake bottoms, except near shore, are covered with soft carbonaceous marl.

The clay is highly plastic when wet but on drying it shrinks with the formation of large cracks and becomes quite hard. The coarse material in the clay is mostly Paleozoic limestone but sandstone, quartzite, gneiss, granite and, more rarely, other rocks are present. Boulders range up to over 7 feet in diameter and most of them are rounded. Many limestone boulders show glacial striae. In contrast, boulders and cobbles on the beaches are smaller in average size and are much more angular than those in the boulder clay. The west-facing beach at Farleys Point on Cayuga Lake is an excellent example of a beach developed on glacial till, and it has been under intermittent observation by the writer for over 40 years.

Farleys Point is a double-headed peninsula jutting into Cayuga Lake from the eastern shore, 1.5 miles southwest of Union Springs. A westward-projecting headland is called Round Point, and one extending northward, Long Point. A profile and section surveyed at right angles to the west-facing beach of Long Point is shown in figure 1. The ground surface is convex upward where it slopes toward the lake and very slightly con-

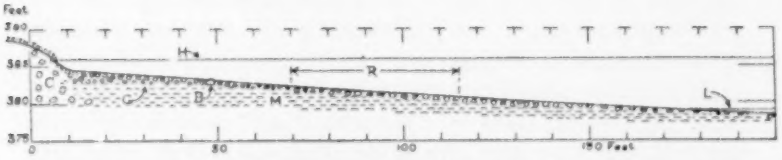

Fig. 1. Profile and section across beach at Farleys on Cayuga Lake, New York. H, high water level; L, low water level; B, location of boulder shown in plate 1; C, boulder clay; G, gravel; M, fine mud; R, area where ruptured cobbles shown in figure 2 were obtained.

cave below high water level. The till in which the waves have been cutting is variable in thickness, but, near the line of section and 400 feet from the shore, a well penetrated 30 feet of the boulder clay.

Under natural conditions lake level was usually highest after spring thaws and lowest during the late fall and winter when precipitation is lowest and runoff is retarded by freezing temperatures. However, high water may occur occasionally at any time during the year as a result of abnormally heavy rainfall. In recent years the water level has been regulated by the Department of Public Works of the State of New York which operates the spillway gates and lock of the Barge Canal at the foot of the lake. The water is drawn down in the fall to prevent property damage from ice piled up by onshore winds. During the 6-year period, 1943-1948, the maximum elevation of the lake at the lock, as recorded by the Department of Public Works[1], occurred each year between May 13 and June 19, and varied between 384.8 and 386.4 feet above mean tide. The minimum elevations occurred between February 9 and March 10, and varied between elevation 379 and 380.4 feet. The high-water and low-water lines are, therefore, separated vertically by 7.4 feet, and the horizontal distance between them is 170 feet.

The mean annual temperature at Auburn, near the foot of the lake is 47.3°F., the average minimum temperature is 15.1° and the lowest temperature recorded is —20°. The average date of the earliest killing frost is October 17 and the average date of the latest killing frost is May 2 (Martin, 1934, pp. 26-28).

The west-facing beach at Long Point is protected from south and east winds but is exposed to winds from the north and west. Winds blowing from a little west of north have an 8-mile stretch of water in which to build up waves large enough to cause considerable abrasion, as is proved by the presence of pieces of rounded and frosted glass.

Gravel thrown up by storm waves above high water level rests on till, but a few feet lower it rests on soft mud derived from the till, and this mud grades through calcareous mud into typical fresh water marl a short distance beyond the low-water line. The gravel is from 1 to 2 or more feet thick near the upper

[1] Letter from Mr. Wm. Robinson, District Engineer, dated Sept. 7, 1949.

margin of the beach but, lakeward, gradually becomes thinner, and beyond the low-water line only scattered cobbles are present. A few widely separated stones found in deeper water may have been ice-rafted from the shore.

The two largest boulders on the beach have maximum diameters of 6 and 7 feet. Most of the smaller boulders have been removed in recent years for use in building protective walls in front of cottages facing the lake. Most of the limestone cobbles are about 5 inches in diameter with a tendency toward tabular form. They commonly rest in the mud with a flat side up, the larger ones being more or less surrounded and separated by slightly smaller ones. This imperfect pattern is probably due to wave action.

Most of the cobbles are angular to subangular (plate 1), but many cannot be so simply described, for flat and irregular surfaces with sharp edges occur on the same specimen with well-rounded surfaces. Many water-worn cobbles have been broken so recently that the fragments have not had time to become separated, though wave action and movement of lake ice soon displace such fragments. Seven angular fragments from a brick were found scattered over an area of 20 square yards.

Some typical cobbles, fractured without separation of the fragments, are shown in figure 2. They were all picked up in shallow water within an area of 300 square yards (fig. 1). Similar specimens are common throughout most of the area between the high- and low-water lines. They are most abundant in early summer when, over large areas, they average one or more to 100 square feet, and, locally, may have a density of more than 10 to 100 square feet. Cobbles with vertical or steeply inclined fractures are easier to find but horizontal fractures are perhaps commoner. Most cobbles are broken into two fragments (fig. 2, B, D, E, F) but some are broken into several (fig. 2, A, C). Fragments of a limestone boulder 3 feet in diameter, deeply embedded in mud have remained in place for several years. Some boulders show discontinuous, incipient fractures which, in a year or two, are enlarged and extended with complete separation of fragments. The incipient fractures show up as dark lines on smooth, dry surfaces because of capillary water drawn up from the wet mud in which the boulders are embedded.

Cobbles of sandstone, quartzite, granite and gneiss, in contrast with those of limestone, are mostly well rounded, and only two were found that had been recently broken (fig. 2, F and plate 1). Each of these cobbles has a single smooth, flat surface, apparently a bedding plane, with sharp edge where it cuts the rounded surface. The matching fragments were not found.

No recently fractured boulders or cobbles were observed on the lake floor beyond the low-water shore line, and the few present near the high-water shore line, where the gravel is thickest, may have been brought up by storm waves or ice. The largest boulders and blocks of limestone on the beach seem to be more resistant to rupture than smaller ones for they show no evidence of recent cracks.

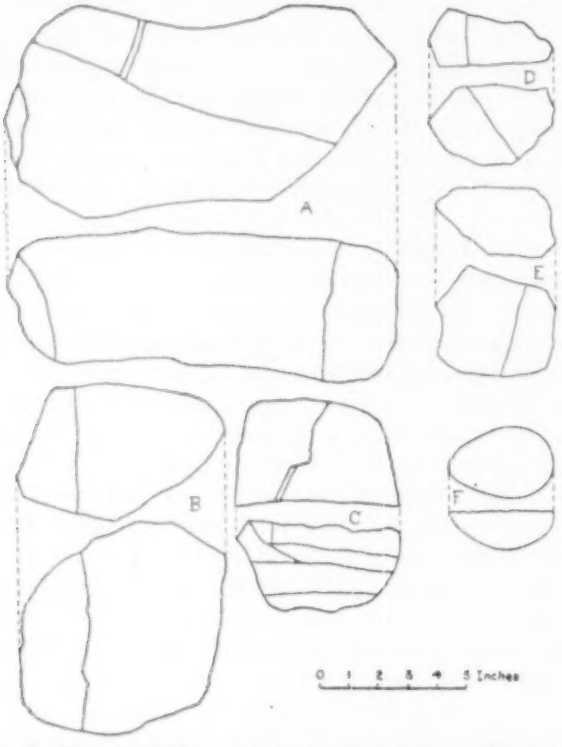

Fig. 2. Profiles of cobbles ruptured by frost action without separation of fragments. A, B, C, D, E, dense-textured limestone; F, coarse sandstone. These cobbles were obtained from the area "R" in figure 1.

A typical view of the mixture of angular, subangular and rounded cobbles present on the beach is shown in the photograph (plate 1) taken in the late summer of 1949 when the lake level stood at 383 feet above mean tide. The cracked boulder in the foreground is well embedded in mud while the smaller cobbles around it rest on other cobbles. The boulder is located about 40 feet from the high-water shore line and at an elevation of 383.2 feet.

BEACHES WITH THICK GRAVEL DEPOSITS

Good examples of beaches with thick gravel deposits are found at the mouth of Big Gully Creek, 2.5 miles southwest of Union Springs, and at Meyers Point, near Ludlowville, where Salmon Creek reaches Cayuga Lake. The gravel, as indicated by the abundance of erratics, has been derived mostly from the till. Boulders, cobbles and pebbles are well rounded, angular fragments being very rare. The high degree of rounding is due to abrasion during stream transportation as well as the later abrasion by wave action, but a more important factor is the absence of recent fracturing which is so noticeable where cobbles rest on clay or mud. The rupturing of cobbles without displacement of fragments is not taking place on beaches with thick gravel deposits.

BEACHES OF SAND, SILT OR MUD

On beaches where only sand, silt and mud are present it is difficult to determine by direct observation the extent to which the coarser particles are being broken up, and the relative importance of the various factors involved.

SHALE BEACHES

The commonest bedrock exposed along the lake shores is shale, which in places, forms high cliffs. It disintegrates readily so that beach material consists chiefly of small fragments of shale. A few erratics from the glacial drift are commonly present and most of these are well rounded. In some places spheroidal concretions are also found.

LIMESTONE SHORES

The limestone beds are too thin to form high cliffs but, in places, as at Round Point and at Frontenac Island, 0.5 mile west of Union Springs, they form low walls and are exposed on the lake bottom. In shallow water limestone blocks and a few erratics rest on the bare limestone, but in deeper water the bed-

rock is completely covered by lake mud. The limestone is broken by jointing into large blocks which show no evidence of recent fracturing.

EXPERIMENTAL EVIDENCE

The extensive rupturing of beach cobbles and boulders cannot be ascribed to impact, wetting and drying, or simple changes in temperature, for these agencies are as active, if not more active, on beaches with thick gravel deposits as on those where the stones rest on clay and mud. Moreover, impact would tend to separate fragments at once, and cobbles that are under water much of the year are subjected to fewer cycles of wetting and drying and to smaller and less frequent temperature changes than those continuously exposed on land. The elimination of these agencies leaves frost action as the explanation of the rupturing, and this process was investigated experimentally in both field and laboratory.

All cobbles and boulders used in the experiments were obtained in digging a well at Farleys Point. Some of these cobbles and boulders were embedded in surface clay 75 feet from the lake shore, some were placed in and on the thick deposit of gravel near the high-water line, and some were embedded in lake mud at points between high and low water. No stones placed on gravel have been broken although exposed for 10 or more years. Most of the boulders embedded in lake mud have been ruptured.

A rounded limestone boulder, 14 inches in diameter, showing glacial striae, was unaffected after 5 years' exposure while resting on well-drained clay, but, when removed to the beach mud, it was broken into 9 angular pieces during a single winter. A subrounded boulder, 18 by 10 by 7 inches, was broken lengthwise the first winter after being placed in the beach mud. The following winter an incipient fracture developed which was extended during the third winter so as to again split the stone.

Small boulders embedded in clay 75 feet from the lake, where surface drainage was fair, remained unbroken for several years until conditions favorable for frost-splitting occurred and then several were cracked. Brick and slate embedded in soil remained unchanged for several years in South Carolina but a single freeze, coming when the ground had been thoroughly saturated by warm rain, caused extensive fracturing and disintegration.

A standard method of testing the weathering properties of

stone, brick and cement is to saturate the samples by submersion in water, after which they are removed and subjected to freezing temperatures. This process is repeated several times, the specimens being weighed after each cycle to determine the loss through disintegration. The writer has modified this test by surrounding the sample with insulating material, the upper surface being exposed to refrigeration while the lower part of the specimen is kept saturated with water. The apparatus is essentially the same as that used to freeze soils in open systems where water can enter or be expelled from the soil during the experiment (Taber, 1929, 1930a and 1930b). Blocks of stone, brick and cement, in open systems, require fewer cycles of freezing and thawing to bring about a given amount of disintegration than when they are tested by the old method.

DISCUSSION AND CONCLUSIONS

In the writer's experiments, coarse-textured soils frozen in a system open with respect to water did not heave because ice merely filled existing voids, the excess water resulting from volume change being expelled; but, when fine-grained soils were similarly frozen additional water was drawn into the soil to build up masses of ice, and the heaving greatly exceeded that which could be attributed to change in volume of the water frozen. In the latter case the pressure effects were due to growth of ice crystals, the pressure being exerted in the direction of crystal growth which is determined by the direction of cooling, except when resistance to growth is much greater in that direction than in others. When highly colloidal bentonitic clays were frozen the heaving was equivalent to the change in volume of the water frozen because water could not enter or leave the impermeable clay during the experiment. In nature, as previously stated (Taber, 1930b, p. 116), there is a gradation, and not a sharp demarcation, between open and closed systems.

Stones behave very much as soils when frozen under similar conditions. Coarse-textured stones, such as sandstones, are seldom fractured because some interstitial water is expelled by the growing ice crystals; but, in fine-grained limestone additional water can be supplied to growing ice crystals from the underlying wet soil if downward freezing is sufficiently slow. It must be slow since a dense-textured stone is highly resistant to rapid flow of water. The larger blocks and boulders of limestone are seldom cracked by frost action, partly because of

high resistance to the growth of a few small ice crystals, and partly because the resistance to the passage of water through the minute pore spaces increases with the distance it has to travel.

Boulders resting on soil, but not deeply embedded, cool rapidly because of the high percentage of their surface exposed, and too rapid downward freezing may prevent ice crystals from enlarging the space they occupy and causing rupture. If the voids are relatively large ice may form downward through these spaces expelling surplus water, but if the voids are sufficiently small the resistance to rapid movement of water may exceed its tensile strength, which in small columns is surprisingly high, consequently cutting off the supply of water to the ice crystals.

The freezing isotherm descends more slowly in clay where a larger amount of water must be frozen than it does in stone where only a little water is available. Therefore, ice crystals may grow in a cobble for some time before the flow of water from clay to embedded stone is stopped by freezing. As winter approaches soil water freezes long before lake water, for much heat must be removed from the large volume of lake water to reduce the temperature at the surface to the freezing point. Lakes, therefore, tend to retard the freezing of mud and clay at, or close to, lake level. As the water is lowered in the fall the mud in which cobbles are embedded is saturated with water at approximately the temperature of water along the lake shore.

Limestone cobbles resting on gravel are seldom fractured by frost action because (1) insufficient water is present in the cobble, or (2) water cannot enter the limestone to feed growing ice crystals. Good drainage makes it difficult to saturate a cobble that is above lake level, but this explanation would not apply to cobbles that are partly submerged. Laboratory experiments (Taber, 1930b, p. 122) show that water occupying very small voids in fine-grained soils may be undercooled in the immediate vicinity of ice crystals but this is not true of coarse-grained soils. Similarly, water in the minute voids of the limestone may remain unfrozen while the 0°C. isotherm descends below the cobble where water occupying the large voids in gravel is promptly frozen, thus cutting off all upward movement of water into the cobble.

Cobbles and boulders embedded in clay at a distance from

Plate 1. Angular beach cobbles at Farleys Point on Cayuga Lake, New York. Half of a well-rounded sandstone cobble is shown immediately in front of the frost-split boulder.

the lake seldom fracture except when freezing occurs after the clay has been thoroughly saturated by rain, melting snow, or the concentration of water near the surface as a result of freezing and thawing.

Limestone cobbles and boulders on beaches underlain with fine mud are more or less angular because they are being ruptured by frost action faster than the fragments can be rounded by abrasion. The other types of rock present are much less susceptible to frost-splitting and therefore are mostly well rounded. On beaches with thick gravel deposits conditions are unfavorable for frost-splitting, and, therefore, cobbles of all rock types become well rounded. Recognizable fragments of shale are seldom present in the boulder clay or on the beaches, except where shale beds are exposed. Because of its cleavage and texture it is easily broken and disintegrated by frost action.

Extremely low temperatures are not required for the intensive splitting and disintegration of rock by frost action. A temperature of a few degrees below 0°C. is sufficient if the rock is fine grained and permeable, and if conditions permit the maintenance of saturation during freezing. In the absence of these conditions frequency of the freezing cycle is of little importance. Writers in the field of frost action have rather generally overlooked the fact that the growth of ice crystals in soils and rocks, with the development of pressure, is controlled by not one but by several factors, including size of pore spaces, size of particles, permeability, resistance to the enlargement of voids, rate of cooling and the availability of water. Resistance to crystal growth is generally greater in rock than in soil, and less uniformly distributed. Therefore location of fractures in rock often occurs along bedding planes and other loci of weakness. Thin tabular specimens of limestone are usually broken in a direction parallel to the smallest diameter. The principles developed in this paper have important engineering applications.

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DEVONIAN MICROFOSSILS, ANDREWS COUNTY, TEXAS

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ABSTRACT. A fossiliferous interval containing conodonts and questionable trochiliscids (Charophyta) from the lowest Devonian rocks of the Three-Bar field, Andrews County, Texas, is interpreted as a stratigraphic admixture of Devonian age. This is evidence indicating a Devonian age for the pay zone of the Three-Bar field.

CONODONTS and questionable trochiliscids (charophyte oogonia) occur in a thin, glauconitic sandstone at the base of the Devonian chert in the Three-Bar field, southwestern Andrews County, Texas. These fossils were first recognized in cuttings from depths of 8470 to 8480 feet in the Stanolind Oil and Gas Company's University No. 2 "AG". Larger quantities of fossiliferous material, obtained subsequently by diamond coring in the Stanolind Oil and Gas Company's University No. 4 "AJ", permitted a more thorough study of the fossils, which disclosed important evidence regarding the age of the pay zone of the Three-Bar field.

The Stanolind Oil and Gas Company's University No. 4 "AJ" is located 660 feet from the north and west lines of section 9, block 11, University Lands Survey, Andrews County, Texas. The description of the core recovered from depths of 8281 to 8286 feet is as follows:

Devonian	Feet	Inches
Smoky-gray, dense, vitreous chert with irregular masses of buff chalky chert	0	7.75
Green, glauconitic sandstone; interstices filled with iron sulfides, calcite, and pale green clay. Contains conodonts, conical fish teeth or scales, and tentatively identified internal molds of trochiliscids	0	1.25
Silurian		
Pale gray to green shaly limestone	4	0

Total depth 8286 feet.

When the glauconitic sandstone from the base of the Devonian was immersed in water and boiled, it disintegrated and the microfossils were freed. The fossils were concentrated by

hand-picking with a small moist brush under a wide-field binocular microscope. All the fossils are amber-colored and the tentatively identified trochiliscids are soluble in acetic acid.

The general geographic and stratigraphic setting of the fossiliferous sandstone is shown in figures 1 and 2. It is immediately below the pay zone of the Three-Bar field and above a gray to green shaly limestone assigned to the Silurian on the basis of lithology and local usage. The fossils are illustrated on plate 1 and are listed as follows:

Conodonts

Icriodus expansus Branson and Mehl (platform)
Icriodus sp. (platform)
Oistodus sp. (simple cone)
Acontiodus sp. (simple cone)
Cordylodus sp. (simple cone)

Fish Remains

Small, low, conical fish teeth or scales.

Algae (Charophyta)

Questionable internal molds of trochiliscid oogonia.

Ninety per cent of the specimens found belong to the conodont genus *Icriodus*. Slightly less than 10 per cent of the specimens are questionable trochiliscids and a minor number are simple cone conodonts and low, conical fish teeth or scales. The simple cone conodonts are fragmentary and show evidence of abrasion. The low, conical fish teeth possess a distinct layer of enamel on their exterior.

The interpretation of the age of these fossils is based mainly on conodonts. *Icriodus expansus* Branson and Mehl is recorded from strata of Middle and Upper Devonian in the United States and the stratigraphic range of the genus *Icriodus* is recognized as being Middle and Upper Devonian (Branson and Mehl, 1938, pp. 156-161). A gap occurs in the knowledge of conodont faunas in the Lower Devonian because none have been described from that part of the system. The possibility that *Icriodus* may range into Lower Devonian, therefore, cannot be completely eliminated. The forms illustrated here are not similar to the genus *Icriodina*, which occurs in the Silurian of Kentucky (Branson and Branson, 1947, pp. 550-551).

The simple cone conodonts are interpreted as Silurian or Ordovician forms, reworked, and included in the glauconitic sandstone. There were ample source beds of Silurian or Ordo-

vician age to supply these reworked specimens. The low, conical fish teeth or scales are not known to have any value as age indicators.

The tentatively identified internal molds of trochiliscids are important in that trochiliscids are known only from the Middle and Upper Devonian and Lower Mississippian beds in the United States (Peck, 1934, p. 97). Their lowest stratigraphic occurrence is near the base of the Middle Devonian. However, trochiliscids are like conodonts, in that Lower Devonian occurrences are not known but the possibility of their existence in that part of the system cannot be ruled out.

The specimens shown on plate 1, figures 1-6, compare favor-

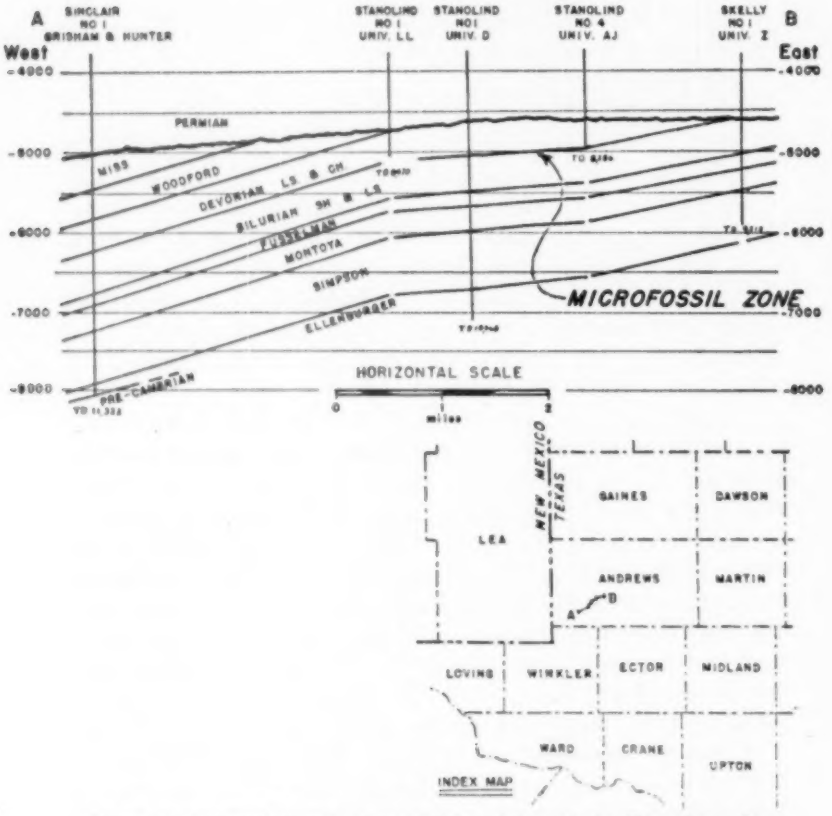


Figure 1. Geographic and stratigraphic setting of the Devonian microfossils.

ably with Peck's (1934, plate 12, figures 1-3) illustrations of internal molds in all respects except size: Peck's specimens are approximately three times as large. After examining the Three-Bar specimens, Peck wrote that they "do look like the internal molds of trochiliscids that I figured some time ago. I compared your material with the figured material and the resemblance except for size is remarkably close. The material I figured was from the Bushberg and the Devonian trochiliscids are much smaller. The size differential should not mean much. My means of identification of the material I figured was association and inference. The material you sent is unquestionably organic and I would not know where else to place it. At the same time, I could not possibly prove the material to be internal molds of trochiliscids" (personal communication, January 3, 1950).

In summary, the data and interpretations made above show this assemblage of microfossils to be a stratigraphic admixture of Devonian age. Silurian or Ordovician simple cone conodonts

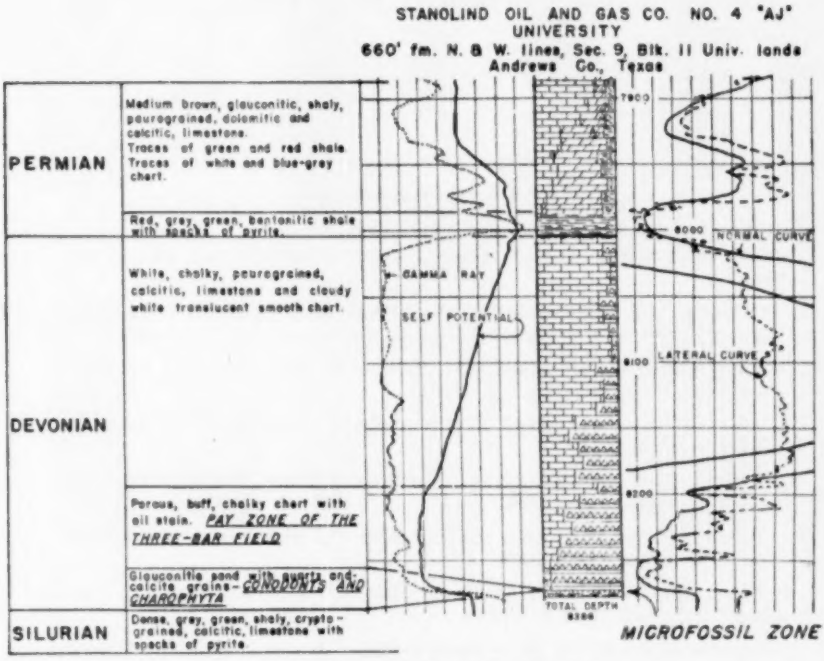

STANOLIND OIL AND GAS CO. NO. 4 "AJ"
UNIVERSITY
660' fm. N. & W. lines, Sec. 9, Blk. 11 Univ. lands
Andrews Co., Texas
PERMIAN
Medium brown, glauconitic, shaly, pauvegrained, dolomitic and calcitic, limestone.
Traces of green and red shale
Traces of white and blue-grey chert.
Red, grey, green, bentonitic shale with specks of pyrite.
DEVONIAN
White, chalky, pauvegrained, calcitic, limestone and cloudy white translucent smooth chert.
Porous, buff, chalky chert with oil stain. PAY ZONE OF THE THREE-BAR FIELD
Glauconitic sand with quartz and calcite grains-CONODONTS AND CHAROPHYTA
SILURIAN
Dense, grey, green, shaly, crypto-grained, calcitic, limestone with specks of pyrite.
GAMMA RAY
SELF POTENTIAL
7900
8000
INTERNAL CURVE
8100
LATERAL CURVE
8200
TOTAL DEPTH
8288
MICROFOSSIL ZONE

Figure 2. Detail of Stanolind well No. 4 (see fig. 1).

have been reworked and deposited in a basal sandstone containing Devonian conodonts and trochiliscids. Correlations with other faunas and floras in the United States indicate an age of Middle and Upper Devonian. However, a Lower Devonian age cannot be ruled out because of the lack of knowledge concerning Lower Devonian conodonts and trochiliscids. In any case, the interpretation given is evidence for assigning a Devonian age to the Three-Bar pay zone, which is immediately above the fossiliferous sandstone.

Acknowledgment is made to The Stanolind Oil and Gas Company for permission to publish the report; to R. E. Peck for examining the trochiliscids and for permission to quote his personal communication; to Mrs. Alberta Early for picking the specimens; and to A. H. Deen, R. K. DeFord, and J. T. Lonsdale for suggestions and criticisms of the manuscript. The photographs of the fossils were made with the financial aid of grant number 276 of the University of Texas Research Institute. The figured specimens are deposited in the paleontological collection of the University of Texas Bureau of Economic Geology.

Explanation of plate 1

All figures magnified 30x

All specimens from the Stanolind Oil and Gas Company's University No. 4 "AJ", southwestern Andrews County, Texas, at depths from 8281 to 8282 feet.

Figures 1 - 7. Questionable internal molds of trochiliscids (Charophyte oogonia). University of Texas Bureau of Economic Geol. No. 19293.

Figures 8 - 13. Unidentified fish teeth or scales. University of Texas Bureau of Economic Geol. No. 19294.

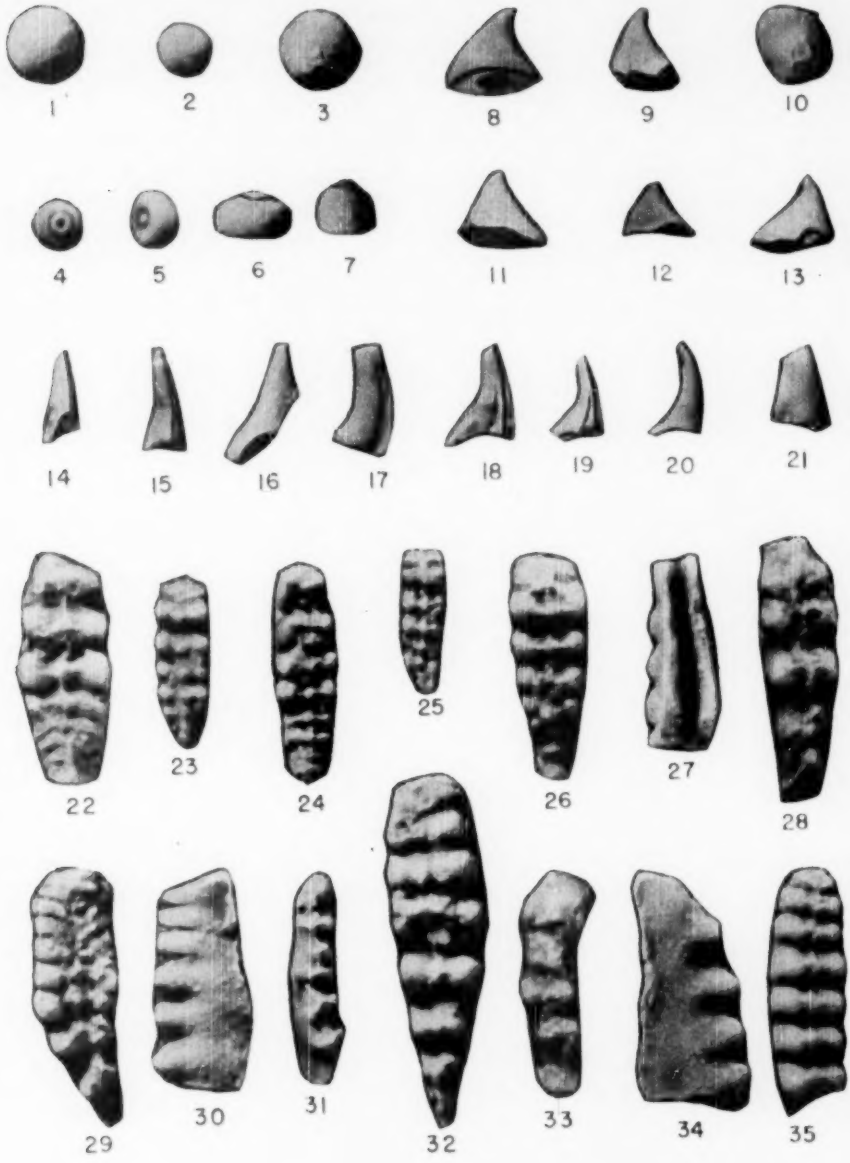
Figures 14 - 15. *Acontiodus* sp. University of Texas Bureau of Economic Geol. Nos. 19295, 19296.

Figures 16, 17, 21. *Oistodus* sp. University of Texas Bureau of Economic Geol. Nos. 19297, 19298, 19299.

Figures 18 - 20. *Cordylodus* sp. University of Texas Bureau of Economic Geol. Nos. 19300, 19301, 19302.

Figures 22 - 28, 31, 33. *Icriodus* sp. University of Texas Bureau of Economic Geol. Nos. 19303 to 19311.

Figures 29, 30, 32, 34, 35. *Icriodus expansus* Branson and Mehl, University of Texas Bureau of Economic Geol. Nos. 19312 to 19316.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EQUILIBRIUM THEORY OF EROSIONAL SLOPES APPROACHED BY FREQUENCY DISTRIBUTION ANALYSIS

ARTHUR N. STRAHLER

PART II

SIGNIFICANCE TESTS APPLIED TO SLOPE PROBLEMS IN THE VERDUGO AND SAN RAFAEL HILLS, CALIFORNIA

Introduction—Studies of the significance of differences in sample means have applications in the attack upon a number of fundamental geomorphic problems involving factors which affect equilibrium of graded slopes. Data collected in the Verdugo and San Rafael Hills, Los Angeles County, California, have been examined with a view to determining (1) if differences in underlying rock type are associated with differences in slope angles, (2) if differences in directional exposure to sunlight and other meteorological factors produce differences in slope angles, and (3) if slopes decline in angle when left to weathering and erosion processes not accompanied by basal erosion and removal.

Description of the Area.—For initial research three small areas in the Verdugo and San Rafael Hills were studied (figure 10). These lie in the southern side of a single NW-SE trending

Figure 10.

Coast Range block of moderate relief (Miller, 1934). Conditions of climate, vegetation, relief and tectonic history are essentially the same throughout, but lithologic factors are not. The easternmost area is underlain by a relatively homogeneous mass of Wilson diorite; the western two areas by the metasediments and small intrusive bodies comprising the San Gabriel formation. Despite marked variations in bedrock composition and structure in the latter formation, the entire southern side of this range appears homogeneous in topographic aspect.

The field work was concentrated upon measuring slope angles in several categories, in measuring and plotting detailed topographic profiles from ravine floors to divides, and in determining the number and location of the smallest discrete channels of the drainage network. Information was plotted on photostatically enlarged copies of the U. S. Geological Survey

topographic maps on a scale of 1:24,000 corrected on the basis of air photograph study and field inspection (fig. 11).

Topography.—Mountain topography of the Verdugo and San Rafael Hills is in a mature stage of development. The drainage pattern is roughly dendritic, although the predominant trend of streams is southwesterly, from the major divide in which the streams head, to the sloping fan surfaces which encroach from the south upon the ragged foothill belt of the mountain base. Although there are many irregularities of bedrock composition and structure, these seem to have rather minor influences upon the placement of minor streams and divides.

Slopes are steep (plate 1), with a tendency to straightness of profile (figs. 1 and 12). Divides tend to be smoothly rounded throughout, a form emphasized by the fact that firebreaks are made and maintained by bulldozer along the major divides. Serrate crests and craggy peaks, often seen in desert moun-

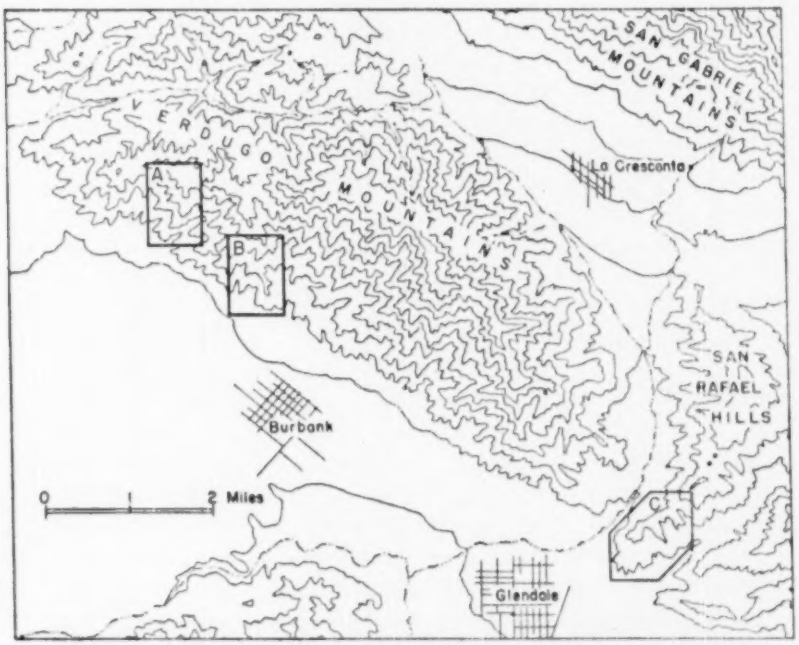

Fig. 10. Outline map of Verdugo and San Rafael Hills, Los Angeles County, California.

tain ranges and glaciated mountains are absent here. Relief is not great, despite the steep slopes. The areas studied have less than 1000 feet total relief while most slope profiles measured in the field have less than 100 feet of difference in elevation from divide to channel.

Ravines may be subdivided into two classes: (1) The smaller ravines and the upper ends of the larger ones are V-shaped in transverse profile. The enclosing walls have slopes in the range 40° to 45° for the most part. The stream channel, dry most of the time, is narrow and is cut in bedrock. Locally, however,

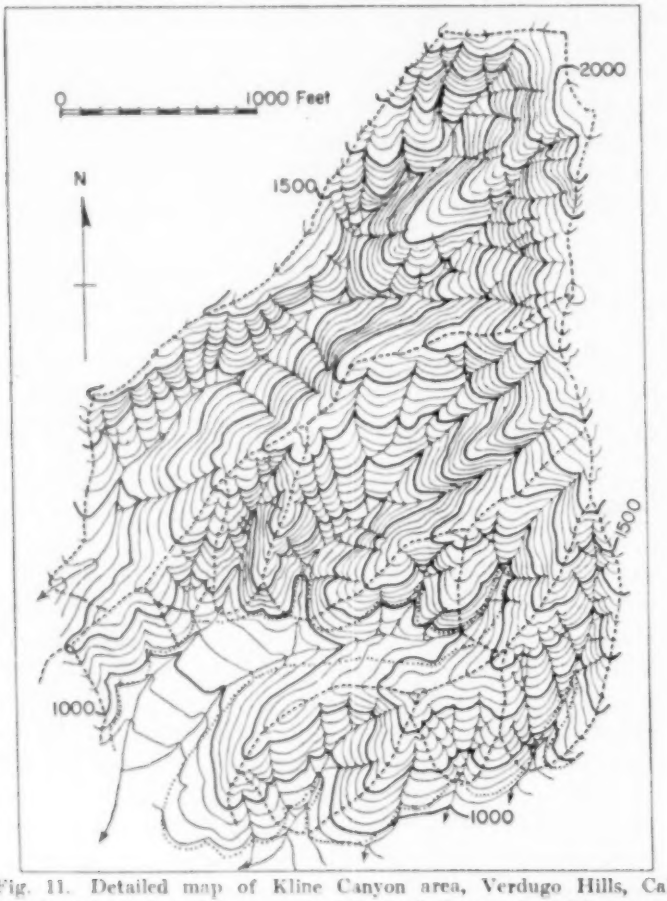

Fig. 11. Detailed map of Kline Canyon area, Verdugo Hills, Calif. (area A of figure 10.) Enlargement of U. S. G. S. map, 1:31,680, corrected in field.

the channel is choked with debris which has slid, rolled or flowed from the steep walls. (2) The lower courses of most of the larger canyons are graded and have a flat alluvial floor ranging from a few feet to one or two hundred feet wide. To what extent the flat is due to lateral corrasion in bedrock, rather than to alluviation by flood- and mud-flow of a formerly V-shaped valley is not easily determined. In the areas studied, a period of recent channel trenching showed alluvial and mud-flow fill. Streams strongly impinge on the base of the steep canyon walls, undercutting the bedrock. Where the stream has temporarily moved away from the slope base steep cones of talus have been built, causing a smoothed, concave-up basal slope of accumulation to be present.

Ravine heads are steep-walled, funnel-like amphitheaters which may be termed "hoppers" because their converging slopes feed detritus into the uppermost end of the stream channel. Hopper walls tend to be nearly straight in profile and to make the form of an inverted part-cone. Most hopper walls are very steep, above 45° in angle. Evidences of rolling and sliding of weathered rock are conspicuous. Bedrock exposure comprises from one-third to three-fourths of the hopper walls. Locally a layer or lens of resistant rock may produce a nearly vertical cliff, but for the most part the rock surfaces conform closely with the straight hopper walls.

Some hopper walls intersect the broadly rounded divide with a sharp, clearly defined break in slope, indicating the rapid expansion of the steep hopper slopes by rapid mass movement into a more stable profile determined by slower processes of creep and rain-wash. Elsewhere the hopper walls merge smoothly into the rounded divide profile and suggest a more nearly balanced slope condition.

The lateral slopes which extend from divide to ravine bottom are characteristically straight in profile for a considerable part of their length (fig. 12). At the upper end the profile merges smoothly into the curve of the divide; at the lower end the straight profile reaches to the ravine floor. In some ravines a composite profile was found, having a lower, or inner, segment steeper than that above it. This was interpreted as the result of a recent epicycle of accelerated erosion locally affecting some of the canyons.

Between-Area Differences in Slope.—Significance of dif-

ferences in means of three areas was examined for the purpose of determining a possible influence of bedrock on slope. Areas A (Kline Canyon area) and B (Stough Park area) are both underlain by the San Gabriel formation whereas area C (San Rafael Hills) is underlain by the Wilson diorite. Should the means of the first two areas prove to be similar, but to differ significantly from the third, the difference may possibly be due to rock type. Should the results fail to show any significant differences, one might conclude that these particular varieties in bedrock have no noticeable influence. Should the first two areas, both in the same type of rock, differ significantly, but one of them to be the same as the third, we might conclude that factors other than rock type influence slope more strongly.

Histograms of three frequency distributions, one from each area are shown in figure 6. In an earlier section on general distribution characteristics of slopes an analysis of significant skewness and kurtosis was discussed (tables 1, 2). Differences

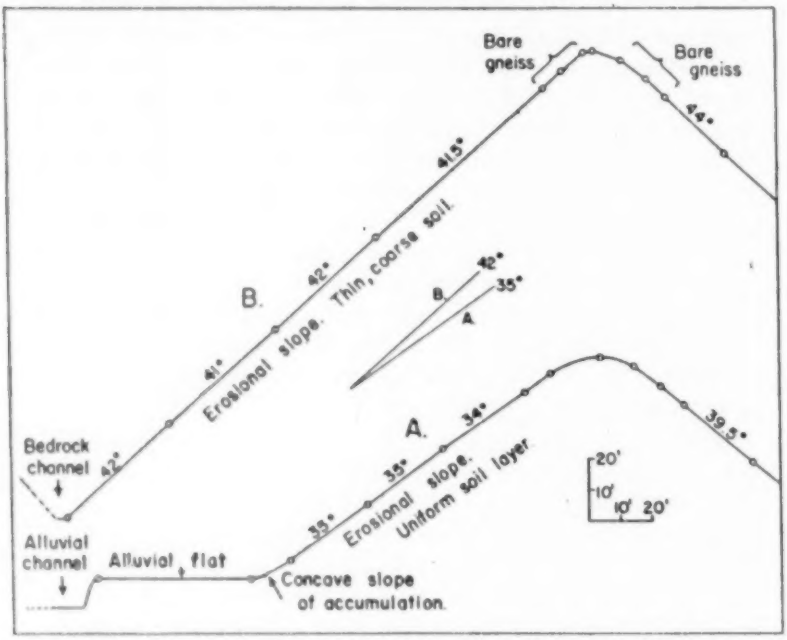

Fig. 12. Surveyed profiles in Verdugo Hills, California. Profile A, representing the type in sample A of figure 14, has escaped basal cutting for a long time. Profile B, representing the type in sample B of figure 14, is being actively corraded at the base.

in sample size are largely the consequence of the prevailing conditions of vegetation at the time of the field work. Area A had been recently burned over and presented an ideal condition for slope work. Area B had a light cover of shrubs following recent burns. Area C was densely overgrown with a chaparral of many years' development.

Tables 4, 5, and 6 give the essential data for the between-area analysis. Tests were made for significance of differences in estimated standard deviations and means.[1] Tests of sig-

TABLE 4

Data used in determinations of significance of differences in standard deviations and arithmetic means (tables 5 and 6.).

DETERMINATIONS	Area A	Area B	Area C
N Number of observations in sample	171	89	26
$\overline{X}$ Arithmetic mean of sample	44.825°	42.084°	42.173°
σ Standard deviation of sample	3.257°	2.522°	2.780°
s^2 Unbiased estimate of population variance	10.669°	6.433°	8.039°

$$s^2 = \frac{N}{N-1}\sigma^2$$

TABLE 5

Tests for significance of differences in standard deviations.

DETERMINATIONS	A and B	A and C	B and C
F (Ratio of larger s^2 to smaller s^2.)	1.658	1.327	1.250
$F = \frac{s_1^2}{s_2^2}$			
n_1 (Degrees of freedom in Sample 1.)	170	170	25
n_2 (Degrees of freedom in Sample 2.)	88	25	88
P. (Ratio of area in two tails of F-distribution to area under entire curve.)	0.02	>.40	>.40
Is there a significant difference in standard deviations?	Yes (?)	No	No

TABLE 6

Tests for significance of differences in arithmetic means.

DETERMINATIONS	A and B	A and C	B and C
t Where $t = \frac{\overline{X}_1 - \overline{X}_2}{s_{\overline{X}_1 - \overline{X}_2}}$	6.90	3.92	0.15
n Degrees of freedom	258	195	113
P Ratio of area in two tails of t distribution to area under entire curve	<.001	<.001	.80 to .90
Are the differences in means significant?	Yes	Yes	No

[1] Analysis was performed by Mr. Richard Ostheimer, Instructor in Statistics, Columbia University.

nificance of differences in estimated standard deviations were required by the differences between area A and the other two areas. As indicated in table 5 there is probably a significant difference between deviations of areas A and B, but not between A and C, or between B and C. Inasmuch as the level of significance in the first case is not minute, we cannot rule out the possibility that they are really not significantly different. Certainly any influence of difference in bedrock fails to show strongly in the estimated standard deviations.

Differences in means are treated in table 6. The results are clearcut in terms of probabilities and satisfactory significance levels. Whereas areas A and C, and areas A and B, are significantly different, the differences in B and C are definitely not significant, with a probability of 80 to 90 per cent that this difference or greater may be due to chance sampling variations alone. Because the two areas of similar rock differ significantly in slope, whereas two of the unlike areas do not differ significantly in slope, we may conclude that some factor (or factors) other than bedrock has a controlling influence on slope differences. These factors might be undetected differences in climate, vegetation, soils, geologic (tectonic) history, or sampling differences due to unintentional changes in sampling method. The conclusions are thus negative, even though clear, and serve to emphasize the complexity of the type of problem being treated.

A possible explanation for a lack of any strong bedrock influence may be the deep weathering of bedrock in this region. Decomposition due to alteration of feldspars and ferromagnesian minerals has proceeded to depths of tens of feet, so that highway grading in bedrock may be done with power shovels. Landforms are thus little influenced by differences in physical characteristics of the unaltered rock.

Influence of Differences in Exposure of Slopes.—Throughout the areas studied there is a marked difference in the appearance of slopes facing south through southeast to east and those facing north through northwest to west. This difference is obvious both in vegetation and soil. In the field one is apt to conclude that systematic differences in slope angle are also present because of the fact that one set of slopes affords better footing for climbing than the other. Whether

or not a slope angle difference actually exists is here investigated by the method of differences in sample means.

All of the areas studied are clothed in a chaparral vegetation representing the natural flora of the region as it develops in various stages following fire. Two distinct types of vegetation are recognizable; that on the drier south-facing slopes, and that on the relatively protected north-facing slopes.

On the south-facing slopes is a light growth, 3 to 5 feet high, termed *chamise-sage* by J. S. Horton (1941). On the south flank of the Verdugo and San Rafael Hills this consists largely of *Adenostema fasciculatum* (Chamise). There are in addition *Eriogonum fasciculatum* (Buckwheat), *Salvia mellifera* (Black sage), *Artemesia californica*, and *Yucca whipplei*. Chamise seems to have excluded almost all other plants except the yucca on foothill slopes which have escaped burning for many years. Slopes burned over recently (3 to 5 years ?) may consist of almost pure stands of *Eriogonum fasciculatum* or *Salvia mellifera* or a mixture of the two, interspersed with some yucca. *Rhus laurina* occurs throughout the chamise-sage areas, making conspicuous dense clumps 8 to 10 feet high and most commonly attaching to rocky parts of the steeper slopes. According to measurements by J. S. Horton (1941) in the San Dimas Experimental Forest, the average percentage of ground occupied by plants is only about 24 per cent, while 76 per cent is open ground. Although no measurements were taken within the areas studied by the writer, it seems likely that there is a similar proportion of open ground. Viewed from opposite hillsides a chamise-sage slope shows a considerable amount of exposed soil, weathered rock mantle, or bedrock.

In contrast with the chamise-sage association is the *chamise-chaparral* association (J. S. Horton, 1941) of north-facing slopes. This is a denser, higher growth, some 8 to 15 or 20 feet high, composed largely of stunted trees. Horton's measurements show that only about 52 per cent of open ground area is present. Viewed from a distance little or no bare ground may be visible. A considerable amount of litter, made up of dead leaves and twigs, is present. In the area studied by the writer, the chamise-chaparral contained such species as *Prunus ilicifolia*, *Rhamnus crocea*, *Quercus dumosa* and *Rhus integrifolia*, intermixed with chamise.

Protection of ground by both of these chaparral associations is considerable, but would appear to be much greater where the chamise-chaparral association is present. On the chamise-sage slopes individual plants catch considerable quantities of twigs and leaves on the up-slope side of the plant base. This in turn holds soil and rock particles, making a miniature terrace. When the slope is swept by fire, much of the debris is released to slide and roll downslope into the ravine bottoms where it accumulates in small talus cones. The bare ground between individual plants or clumps of plants is readily attacked by raindrop beat (splash erosion) and sheet-run-off, which in places has cut small rill channels several inches into the weathered rock mantle. In dry weather these grooves serve as chutes down which loosened particles roll or slide. The activities of rabbits, coyotes, deer and other animals which live in large numbers on chaparral slopes serve to release much fragmental rock and soil material throughout the long, dry Mediterranean summer.

Nature of the soil cover is likewise contrasted on the two types of slopes. The N-NW-W chamise-chaparral slopes commonly have a thick, dark-brown soil through which no bedrock crops out. A maze of fine rootlets binds the surficial part of the soil together so that free sliding and rolling of particles is minimized. The thick soil is given readily to flowage movements; the scars typical of such movements are conspicuous on burned-over slopes. On the S-SE-E slopes with a light chamise-sage cover, soil is thin. Outcrops are numerous and make up a large portion of the surface area of slopes over 40° or 42°. In the absence of soil held by rootlets there is much free rolling and sliding of weathered rock particles. Both because of the greater proportion of outcrops and because of the greater amount of sliding of detrital fragments, these slopes give the impression of being the steeper. They are more difficult to ascend or descend on foot than the soil-covered slopes (where both are freshly burned over) because footing is poorer in the loose unstable detritus on S-SE-E slopes.

In order to determine if a true and systematic asymmetry does exist between the two sets of slopes, a test was set up using slope angles previously gathered without regard for the particular problem of asymmetry. All ravines having simple, opposed valley walls were used; eight in all. These

ranged in trend from N-S to ENE-WSW and showed contrasting slope conditions as previously described. In all cases the ravine was sharply V-shaped with a narrow stream channel occupying the bottom. Thus the deepening of the ravine would cause approximately equal basal corrasion of both valley walls. Due to the complexity of bedrock, which included metasediments and small intrusive bodies, it is not certain that control by rock structure and composition differences is absent. No such relationship suggested itself, however.

Fifty-two readings were analyzed from slopes facing in a westerly or northwesterly direction; 53 from slopes facing southerly or southeasterly. The equality in number of readings was wholly fortuitous, because all available readings were used and none arbitrarily discarded. In general the distribution of readings was even throughout and opposite sides of the same ravine received almost equal sampling.

Of the first group, facing W, NW or N, the arithmetic mean was 44.54°; for the second group, facing S, SE or E, the arithmetic mean was 44.56° (fig. 13). Note that standard deviations differ markedly even though means are almost identical.

A test of significance of difference in means shows

$$\sigma_{\bar{x}_1 - \bar{x}_2} = 0.631$$

$$\frac{x}{\sigma} = 0.03168$$

The area under the two tails of the normal curve is 97.2 per cent. Hence the probability of obtaining this great a difference in means or greater due to sampling variations alone would be about 97 out of 100, if samples were repeatedly drawn from a slope population uniform throughout. It is nevertheless possible that a true difference exists due to exposure but that the two samples happened to have almost identical means. If we take the observed difference, plus or minus 2.6 times the standard error of the difference of the means ($.02 \pm 2.6 \times 0.631$) and we state that the true difference lies somewhere in this range of values, then, if we regularly proceed according to such a rule, in the long run 99 per cent of the statements will be true.

This example serves as an illustration of the value of systematic quantitative measurement and testing in investigating

what seems upon casual field observation to be a difference in slope angles due to exposure to meterological elements. The eye alone cannot detect significant small differences and may, on the other hand, be deceived into registering a slope difference where none exists.

Parallel versus Declining Slope Retreat.—A fundamental problem in geomorphology is whether slopes of a fluvially dissected landmass retreat in parallel planes accompanied by replacement with a set of lower basal slopes, as Penck (1924) has held, or whether they decline to progressively lower angles as the landmass relief is lowered, as Davis (1909, p. 268-269) has held.

Under the equilibrium theory, outlined in earlier pages, slopes maintain an equilibrium angle proportional to the channel gradients of the drainage system and are so adjusted as to permit a steady state to be maintained by the process of erosion and transportation under prevailing conditions of climate, vegetation, soils, bedrock and initial relief or stage. Thus both slopes and streams are graded. In any one small area where homogeneity prevails slopes tend to cluster about a mean value with relatively low dispersion. As the landmass is reduced

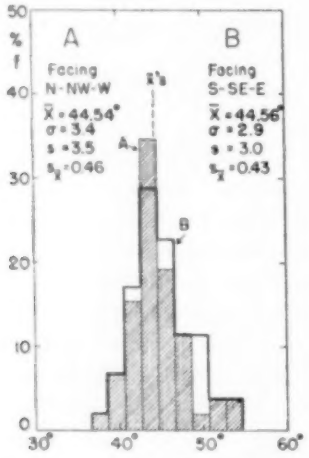

Fig. 13. Histograms of two samples superimposed for comparison. Sample A (cross-hatched) represents the more densely vegetated, sheltered northerly-facing slopes. Sample B (heavy line) represents thinly covered chamise slopes with southerly exposure. Means are almost identical, hence are indicated by one line.

both slopes and stream gradients are reduced, being slowly and continuously regraded to maintain approximate equilibrium. As the correlation of stream gradients with slopes (fig. 8) suggests, the decline of stream gradient is accompanied by slope reduction. This concept of maintenance of a steady state by slow readjustment is essentially Davis' concept of landmass development in the normal cycle.

Under the Penck (1924) theory of landmass development an initially steep slope or wall (*Böschung*) such as the valley wall of a youthful canyon, might be expected to retreat in successive parallel planes. So long as the stream is down-cutting at a constant rate, no other elements of slope would be present and uniform development would prevail. With diminishing rate of down-cutting by the stream there will begin to develop at the base of the steep slope a gentle slope (*Haldenhang*) which expands in area as the steep slope retreats from the valley axis. The *Haldenhang* is, in turn, replaced by still lower slopes (*Subhaldenhänge*). This concept fails to correlate stream gradients with slopes, as the theory of equilibrium forms in a steady state demands. Once formed, a steep slope (*Böschung*) would retreat at a constant angle regardless of changes of gradient of the associated stream.

In the Verdugo and San Rafael Hills the prevailing conditions are those of steep-walled, V-shaped canyons, or canyons with narrow alluvial valley flats. If the topography is developing by parallel slope retreat, as under the Penck theory, there might not yet be any development of *Haldenhänge* because of the rapid valley deepening and widening. It would thus be difficult to draw conclusions as to the correctness of these theories on the basis of general topographic aspect. There is, however, a possible means of determining the validity of Penck's assumption that a steep slope retreats in parallel planes once it has been formed and is no longer subject to direct basal stream action. At various places along the narrow alluvial flats in some of the canyons the stream is vigorously undercutting the bedrock at the slope base on one side, but has not recently been active on the opposite side, where there is an accumulation of soil and rock fragments in the form of talus or basal sheet-wash apron. The slope above this zone of accumulation has been free to waste back by processes of mass movement and sheet erosion, but without any removal or undercutting at the slope base. If retreat has been parallel, slopes of

this type should maintain a mean angle the same as for the slopes vigorously corraded at the base; if retreat has been of the declining type, these slopes should be significantly lower than the latter group.

During the field work measurements were made of erosional slopes which had basal accumulations of slopewash or talus and had, therefore, for a greater or lesser period of time, no vigorous corrasion at the base. In all 33 measurements of this class of slopes in the Kline Canyon area were made. These slopes were located among the slopes being actively corraded, of which the sample of 171 readings has already been described (sample E in figures 2, 3 and 4). The larger sample includes none of the smaller, but the two are intermixed as far as geographic distribution is concerned. Figure 14 shows the histograms of the two frequency distributions plotted on the same coordinates. The mean of the protected slopes is 38.2°; that of the basally corraded slopes 44.8°, a difference of 6.6°. Estimated standard deviation of the first group (2.70°) is somewhat lower than the second (3.27°) but both are of the same general order of magnitude. It is obvious, in view of the significance levels obtained in previously described tests, that a difference in means of 6.6° is significant beyond doubt. A test shows that

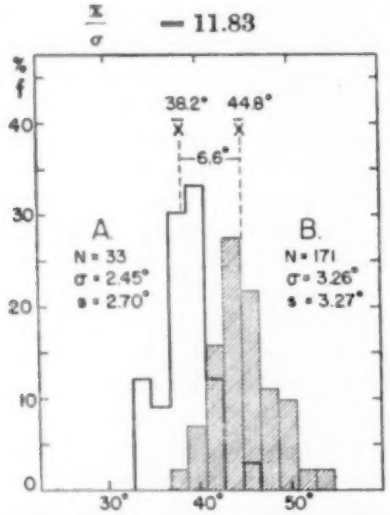

Fig. 14. Histograms of two samples superimposed for comparison. Sample A, protected slopes. Sample B, basally corraded slopes.

Tables of areas under parts of the normal curve fail to include this high a value. If the value were 5.0 the probabilities of obtaining this great difference or greater by chance variations in sampling from the same population would be on the order of one in one million.

We thus conclude that the slopes which have been protected from recent basal cutting have significantly lower angles. The statistical analysis does not explain this difference, but in view of the fact that conditions of climate, vegetation, soils, bedrock, and tectonic history seem to be essentially the same for both samples it is concluded that the one group of slopes declined in angle during the period when only sheet-runoff, creep and other mass-wasting processes operated on the slope. Some suspicion, at least, is thus cast upon the Penck assumption of parallel retreat, while some support is given Davis' scheme of declining slopes.

Summary Statement.—The method of evaluating the significance of differences in sample means appears to have applications in the solution of fundamental problems of geomorphology. The method serves as a check upon the reliability of conclusions drawn from samples. In the three examples described above, the second and third illustrate opposite extremes of significance level which give considerable confidence to the investigator in drawing conclusions. The first case illustrates an inconsistent relationship among three sample means relative to a possible causative factor and points to control by other factors not under consideration.

Although the specific results of this investigation may prove of little consequence in the light of future studies, some value may come through increasing the range of techniques available in the attack upon basic geomorphic problems.

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COMMUNICATION

Evidence of the Taconic Sequence in the Vicinity of Lehigh River, Pennsylvania

In my paper on the Taconic sequence in Pennsylvania (Stose, 1946), the map of the Hamburg klippe, which embraced the known extent of the Taconic sequence in that area (fig. 2 of that paper) is shown as ending west of Lehigh River. Results of renewed study of the shale in the vicinity is presented here.

In the State Survey report on the geology of Northampton County, Penna. (B. L. Miller, *et al.*, 1939), seven inliers of limestone in the Martinsburg shale just east of Lehigh River are mapped. Ralph Miller (1937), who studied these limestones in detail, states (p. 108) "Two lines of evidence favor an Upper Cambrian age for these limestones. 1) There is a lithologic similarity to the known Upper Cambrian beds (Conococheague limestone) of the region. 2) In a number of different exposures, the fossil *Cryptozoon*, which elsewhere in the valley is restricted to the Upper Cambrian, has been found." He says also (p. 110) that these *Cryptozoons* "more closely resemble *Cryptozoon proliferum*," the fossil that occurs in the Upper Cambrian, than a form found in the Trenton limestone at Lake St. John, Quebec. Despite these facts, Ralph Miller could not bring himself to believe that the limestones were Upper Cambrian because the Martinsburg shale at the adjacent south side of the belt is underlain by the full thickness of Jacksonburg limestone and underlying Beekmantown limestone, both dipping gently north, which lie above the Upper Cambrian Conococheague limestone. He states (p. 109) "If unconformity be postulated, it would require that 600 feet of Jacksonburg and 1200 feet of Beekmantown thin out . . . in a horizontal distance of 600 feet. This seems impossible." He therefore concluded that the limestone inliers are local calcareous lenses in the Martinsburg shale, and they are so mapped in the County report (B. L. Miller, 1939).

In 1936 Miss Jonas and I examined the limestone inliers in the shale exposed on Catasauqua Creek north of Weaverville and along the road west through Seemsville to Kreidersville. We observed only one indistinct *Cryptozoon* in a quarry, and the limestone did not impress us as distinctly resembling the Conococheague limestone of the Great Valley. But if it contains *Cryptozoons* "in a number of different exposures," as reported by Miller, this fact cannot be ignored.

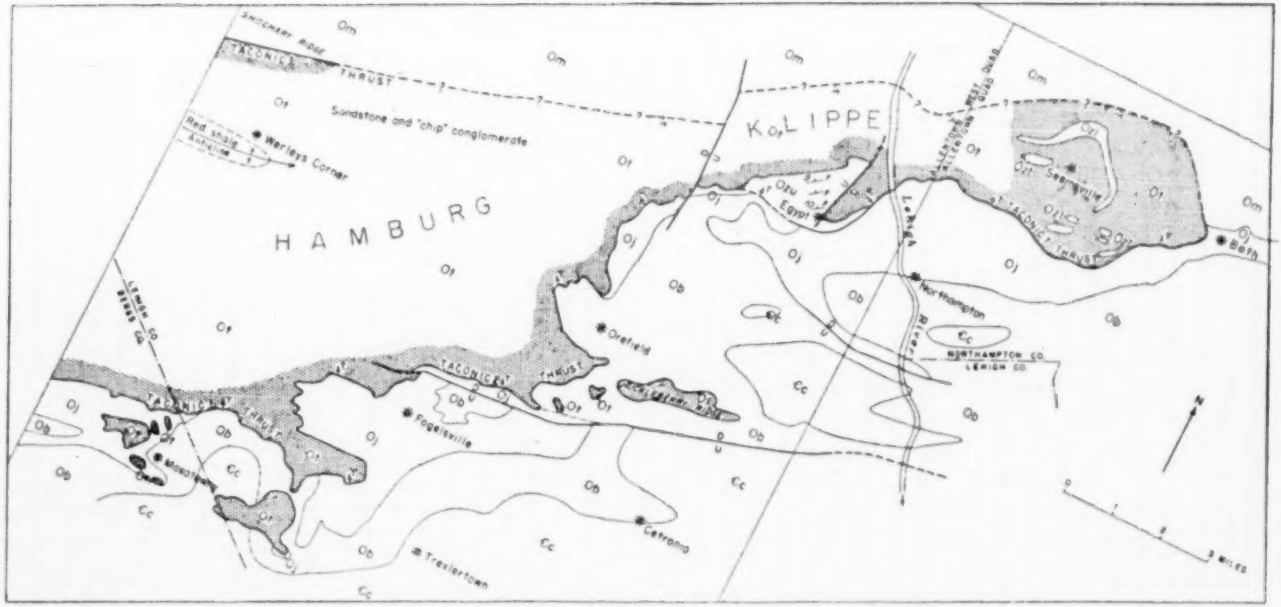
Red shale or other types of sedimentary beds known to be characteristic of the Taconic sequence were not observed in the vicinity of Seemsville, but such beds do occur 15 miles to the southwest

along the strike. The shale near Seemsville does have limestone inliers similar to those in shale at and north of Leesport and at many places farther west, where these limestones have been included in the Taconic sequence (Stose, 1946, p. 676). The limestone inliers in the vicinity of Seemsville, however, seem to be different in that they contain *Cryptozoon* that suggest Upper Cambrian age. The greatly disturbed character of the limestones, their brecciation, and the presence of many injected quartz stringers indicate much movement and possible thrusting. The limestone of the inliers, therefore, may be part of the floor on which the shale was deposited before it was thrust, and was thrust with the shale to its present position.

One mile north of Egypt, west of Lehigh River, the shale, with low north dip, is underlain by nearly horizontal thin-bedded fossiliferous limestone, crystalline limestone, shaly argillaceous limestone, and dolomite. The fossiliferous beds contain trilobites, which Ulrich identified as *Leiostidium* sp. (Stose and Jones, 1927, p. 512), and were referred by him to his "Upper Ozarkian" (lowermost Ordovician), somewhat higher than the *Cryptozoon* horizon of the Conococheague limestone ("Lower Ozarkian" of Ulrich). At the time this observation was published, the shale was regarded as Martinsburg and the underlying "Upper Ozarkian" beds were interpreted as evidence of an unconformity at the base of the Martinsburg. This shale is now regarded by the writer as part of the Taconic sequence and the underlying fossiliferous limestone is interpreted as part of the floor on which it was deposited before it was overthrust to its present position. These beds are in a triangular area west of a north-trending normal fault and north of an east-trending shear zone in the limestone, which is interpreted as the Taconic thrust (fig. 1). It lies just southwest of the Seemsville area of limestone inliers, and supports the interpretation that those limestones are part of the floor beneath the shale of the Taconic sequence that was thrust with it from the southeast.

The shale north of Egypt has no red shale, characteristic of the Taconic sequence, but 10 miles to the southwest, near Werleys Corner (fig. 1), red shale (Behre, 1933, plate 25), which is included by me in the lower part of the Taconic sequence, is in an anticline that plunges east beneath a thick series of sandy beds in which are "chip conglomerate," characteristic of the upper part of the Taconic sequence. All the shales and sandstones in the surrounding area, south of Shochary Ridge, are now tentatively classed by the writer as part of the Taconic sequence.

In my former paper (Stose, 1946, pp. 680-681 and fig. 3), I presented evidence of a thrust fault on the south side of Shochary Ridge whereby the shale of the Taconic sequence was thrust north over fossiliferous upper beds of the Martinsburg shale. This thrust


Om
TACONIC THRUST
Ot
Sandstone and "chip" conglomerate
Red shale
Ordovician
Warleys Corner
HAMBURG
Ot
Kot LIPPE
Ot
Ozu
Ozl
Egypt
Ot
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passes eastward into the Allentown West quadrangle. As indicated on the map (fig. 1), I have included in the Taconic sequence the shale north of Egypt and the shale around Seemsville in which the limestone inliers occur; also all the shale and sandstones south and southeast of Shochary Ridge to the limestones of the Valley. In this area the irregular relation of the shale to the various older limestone formations has been very confusing because the shale was regarded as Martinsburg, but if the shale is overthrust, the irregular relations to the limestones can readily be explained, and confusion ceases to exist. The unconformable relation of the outlying shale area east of Maxatawny to the underlying Beekmantown and Conococheague limestones (B. L. Miller, 1941, geologic map) is made clear by regarding the shale as overthrust, as shown in figure 1. The shale of Huckleberry Ridge and other outlying shale areas east and west of Maxatawny, including the shale just described, are greatly disturbed and suggest overthrusting, and they are interpreted as klippen of the overthrust Taconic sequence.

The Taconic sequence of New York and New England, deposited in the eastern or Levis basin (Ruedemann, 1930, pp. 80-130), is composed largely of shale down to the Lower Ordovician Deep Kill shale, and the underlying Schaghticoke shale is tentatively regarded also of Lower Ordovician age. Beds of Upper Cambrian age and "Upper Ozarkian" of Ulrich are missing in the section. Shales, grits, and some limestones, that are lower in the section and extend down to the Nassau beds, are of Lower Cambrian age. Considering the distance of the Pennsylvania locality from the type area in New York, changes in the character and composition of the section along the strike might be expected, and the Ozarkian and Upper Cambrian, which are not represented in the Taconic section of New York, might be present in Pennsylvania and be represented by limestone and shale, of which the trilobite-bearing limestone near Egypt and the *Cryptozoon*-bearing limestone near Seemsville may be a part. Normanskill graptolites, typical of the Taconic sequence in New York, are present at many places in the Taconic sequence in Pennsylvania, and occur also in the Athens shale in the Shenandoah Valley of Virginia, where the shale is associated with fossiliferous limestones. Deep Kill graptolites, also characteristic of the Taconic sequence of New York, have been found at only one place in the Taconic sequence of Pennsylvania (Stose, 1930, p. 641; 1946, p. 674; 1950, p. 135) and are not known elsewhere in the Appalachians south of New York.

Conclusion.—All of the shale and sandstone that lie south and southeast of Shochary Ridge in the Allentown West quadrangle, extending eastward to Egypt and east of Lehigh River to Seemsville (fig. 1), are probably part of the Taconic sequence; the ir-

regular distribution of the limestone formations beneath the shale and its outliers around Maxatawny, Fogelsville, and Huckleberry Ridge accord with this interpretation. The limestone inliers in the shale around Seemsville containing *Cryptozoon*, and the fossiliferous limestone of "Upper Ozarkian" age beneath the shale near Egypt, may be part of the floor on which the shale of the Taconic sequence was deposited and were thrust with the shale to its present position.

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REVIEWS

Colloid Science, Vols. I and II; by A. E. Alexander and P. Johnson. Pp. xx and viii, 837. Oxford and New York, 1949 (Oxford University Press, $15.00).—Colloid Chemistry is a branch of Chemistry which deals with systems which are neither frankly homogeneous nor outspokenly heterogeneous. The subject touches so many fields that the table of contents, which summarizes the organization of the two volumes, covers 12 pages (this is about three and a half times as many pages as given to the index). The first volume consists of two parts: historical and general survey (5 chapters) and experimental methods and their theoretical basis. This latter part is again subdivided to treat systems as a whole (11 chapters) and the interface (3 chapters). The second volume is Part 3 of the whole work, and deals with the specific colloidal systems: sols, gels and pastes, foams, emulsions, colloidal electrolytes, clays and zeolites, proteins, polymers and membranes. An attempt is made in this part to discuss for each system methods of preparation or formation, structure in bulk and interface, stability, and the more important properties.

This work covers an extraordinarily wide field and, as it seems to this reader, does so in a clear style, with a large number of apt illustrations. It is a pleasure to read this work. In degree of difficulty the work falls between simple texts on colloid chemistry and monographs on very limited subjects. For this reason it can give a broad yet in some cases reasonably detailed treatment of colloid chemistry. This has been needed, and the book may very well become a useful text.

There are two features of the work which are somewhat disappointing. As noted above, the index is very short and is, indeed, quite inadequate. The orderly arrangement of the text and the extended table of contents redeem this situation a little. The other feature is the sparse documentation. References are given at the end of each chapter, but are not very many for a book of this kind.

The authors are to be congratulated on producing a work of such breadth. The two volumes will surely be valuable additions to the bookshelves of many workers in physical chemistry and in those earth sciences which draw on physical and colloid chemistry for support.

HAROLD G. CASSIDY

Albert Einstein: Philosopher-Scientist; edited by Paul Arthur Schilpp. Pp. xvi, 781. Evanston, Illinois, 1949. (The Library of Living Philosophers, Inc., $8.50).—This book is the seventh of a series bearing the general title: *The Library of Living Philosophers*, each volume of which provides a group of interpretations of the work of a celebrated living philosopher by contemporary authorities, and includes the reply of the scholar in question to his commentators and

critics. Prefaced by an authoritative biographical sketch or, whenever possible, by an autobiography, each volume is concluded by a complete bibliography of the subject's writings. Such a plan has interesting possibilities and successful treatments of the work of such figures as Bertrand Russell, John Dewey, and Alfred North Whitehead have already appeared.

The man in the street accustomed by now to hear Albert Einstein acclaimed as an eminent mathematician and more particularly (and more accurately) as one of the greatest theoretical physicists of modern times, may well express surprise to find him here appearing in the guise of a philosopher. In the common view physicists are supposed to be suspicious of philosophers with their well-known penchant for explaining everything in terms of universal "systems," like idealism, materialism, etc., and their equally notorious inability to agree with each other on what really makes the world go round. On the other hand those physicists who have taken the trouble to examine the basic concepts of their science realize keenly how much a re-interpretation of such concepts can mean for future physical theorizing. It was to just such a process of searching analysis that Einstein subjected the ideas of space and time as previously employed in physics, and in so doing created the theory of relativity. If this sort of thing is philosophy, and the enormous interest which it has aroused among professional philosophers appears to indicate that it is, then Einstein certainly is entitled to rank as a philosopher as well as a scientist.

The general reader who approaches this book with the expectation of finding it another primer of relativity will be disappointed. The articles demand, in general, considerable background knowledge of modern physics and many of them dip pretty deeply into the abstractions of physical methodology. For physicists the introductory autobiographical sketch, which is entirely concerned with the genesis and development of Einstein's scientific views, will hold considerable interest, though the translation which accompanies the original German is scarcely adequate.

The twenty-five descriptive and critical essays which constitute the bulk of the volume divide themselves more or less naturally into three classes: (1) those descriptive of certain phases of Einstein's scientific achievements, (2) those relating to the philosophical implications of his work and particularly to his own definitely expressed methodological views, and (3) articles descriptive of certain theoretical developments suggested by or related to Einstein's relativity theory but actually independent of it and hence constituting original contributions. Typical of essays of the first class is the excellent article by Max Born on "Einstein's Statistical Theories." Examples of the second type are provided

by Niels Bohr's "Discussion with Einstein on Epistemological Problems in Atomic Physics," by Henry Margenau's" Einstein's Conception of Reality," and by P. W. Bridgman's "Einstein's Theories and the Operational Point of View." Finally the third class is well illustrated by E. A. Milne's "Gravitation without General Relativity," which is really a boiled-down exposition of Milne's own ingenious theory of kinematic relativity and its application to gravitation.

Though most of the essays stress adequately Einstein's great contribution to modern physical thought, many are rather critical of his methodological views. Of the controversial ones the most interesting to the reviewer is that of Bohr, which is a masterpiece of exposition and brings to the sharpest possible focus the fundamental disagreement between Einstein's views on reality and what constitutes a complete physical theory and those of the modern quantum physicist. In its essence it poses the old problem of the continuum versus the particle viewpoint in the development of physical theories, with Einstein maintaining his faith in the ultimate ability of the former to provide the best explanation of physical reality and with Bohr stressing the peculiar epistemological barrier erected against such faith by the existence of the quantum of action, which ironically enough, Einstein himself did so much to make a vital part of modern physics.

To the properly equipped student the reading of the essays in this volume cannot fail to be a very stimulating experience.

R. B. LINDSAY

Introduction to Statistical Mechanics; by RONALD W. GURNEY. Pp. vii, 268; 59 figs. New York, 1949 (McGraw-Hill Book Company, Inc., $5.00).—One of the outstanding difficulties in grasping theoretical physics is the problem of separating the mathematics and the physical ideas. The subject of statistical mechanics carries with it all of these difficulties. Professor Gurney, already well known for books giving clarification of complicated subjects, has made a real contribution to the presentation of statistical mechanics. The first chapter, in which the basic concepts of the most probable distribution, and of temperature are introduced, should be read by everyone, whether he be already an expert or not. In the light of this simple approach the further mathematical development proceeds smoothly and the topics covered are easily understood.

The book must be regarded as elementary. There is no attempt to consider and contrast the various approaches to statistical mechanics. For example, the material necessary to consider the atomic nucleus from a statistical viewpoint is missing. However, as a basis for understanding chemical and solid state applications the treatment is excellent.

The first half of the book can be thought of as establishing a physically founded statistical method. This is then applied to dissociation equilibrium, solutions and alloys, expansion, condensation, lattice vibration, diatomic molecules, particles in electric fields and electrons in a metal. In every case the treatment is clear and gives a fresh insight.

One minor criticism is the back reference to numbered equations. In many cases it would aid the reader if the actual relation were repeated in place of the reference.

The book has already proved of value as a reference text for an undergraduate senior course. Student comments are favorable. It is clearly written and a pleasure to read. ERNEST C. POLLARD

Nuclear Radiation Physics; by R. E. Lapp and H. L. Andrews. Pp. xiv, 487. New York, 1948 (Prentice-Hall, Inc., $4.50).—The enormous interest in nuclear physics since 1945 has been met with an astonishingly small response in text material. A striking exception to this unfortunate trend is the present well written book by Drs. Lapp and Andrews. It is intended to be read by anyone of scientific training, not necessarily physical in nature; and it includes a brief description of modern atomic physics, including x-rays, before the subject of nuclear physics itself is developed.

The topics covered in about four hundred pages include almost every development of interest up to 1948. For this reason it reads somewhat breathlessly. Thus the subject of beta decay, including Sargent diagrams, Fermi's E^5t relation, Konopinski-Uhlenbeck's modification, is contained in six pages. The compact treatment is excellently conceived and the authors are to be congratulated on the ability to present the essence so well. Nevertheless, from the point of view of the student the problem of assimilation may be difficult. With this one general criticism of density of content one can stop being critical. The diagrams and illustrations are excellent, ranging from simple explanatory diagrams to excellently chosen pictures of complex apparatus or of complex nuclear processes. Worked examples are provided to enable the student to become familiar with the rather surprising numbers of nuclear physics. Good problems are also provided in plentiful numbers.

Most important, the book has the flavor of modern nuclear physics, and is clearly written by authors who have experienced its rapid growth. It is a welcome addition to any bookshelf.

ERNEST C. POLLARD

Procedure in Taxonomy; including a reprint in translation of the Règles Internationales de la Nomenclature Zoölogique (*International Code of Zoölogical Nomenclature*) *with titles of and notes on the Opinions rendered to the present date* (1907 *to* 1947);

by EDWARD T. SCHENK and JOHN H. MCMASTERS; revised by A. MYRA KEEN and SIEMON WILLIAM MULLER. Pp. 93. Stanford, 1948 (Stanford University Press, $2.50).—The many systematists who have relied on this valuable little book for constant reference on matters related to the "International Rules" of nomenclature will welcome the augmented and modernized edition. The conspicuous additions are a brief chapter on the background and activities of the International Commission on Zoological Nomenclature, summaries of Opinions 124-133 and titles of Opinions 134-194. The sequence of chapters has been changed. Some useful new references have been added, and the text has been rather extensively transformed into more precise phrasing. The thorough index has, of course, been enlarged to cover the additions in the revision.

With the expectation that this edition will, like the first, be highly successful and again revised when reprinting becomes necessary, the reviewer must note the continued omission of a few points. (1) The definition of "taxonomy" needs to embrace the recognition and description of species, an aspect at least as important as nomenclature and "the ranking of the various categories." (2) The fact that the term "tribe" has been "variably employed" in the past does not remove it from justifiably wide modern usage for a very definite category in the classification of most groups of animals. As affinities become better and better known the need increases for a regular category between "subfamily" and "genus." (3) Important omissions in the list of types are "cotype" and "allotype." Regardless of the position individual authors may take on these terms, they are so commonly used in zoological taxonomic literature that it is essential that definitions be given in a reference work like this little book. It should also be emphasized in the definitions of "Primary types" that a specimen becomes a primary type only when so designated in a publication; this is a particularly important point for lectotypes and neotypes, for which loose practices are sometimes followed. (4) It is time for the problem of "genotype" *versus* "generotype" to be faced squarely, and the present authors should at least have mentioned the existence of the question. In genetics and systematics the term "genotype" is used for very different meanings. The increasingly wide overlap of these two disciplines makes it imperative that separate terms be used for the two concepts. "Genotype" appears to be firmly fixed and essential to geneticists. Furthermore, it cannot be derived from the combining form of "genus" (*gener-*) and should have been written "generotype" by systematists from the beginning. Such a spelling needs to be incorporated into the *Règles* and the term "genotype" abandoned for the type of a genus.

CHARLES L. REMINGTON

Earth Movements and Organic Evolution. Proceedings of Section L of the International Geological Congress, Report of the 18th Session, Great Britain, 1948. Pp. 59. London, 1950.—In the introduction to this symposium H. L. Hawkins (Great Britain), Chairman, sketches the problems of correlation between "orogenic spasms" of the earth and the speeding up of organic evolution. The subject is of perennial interest and was also a symposial topic at the last meeting of The Geological Society of America and associated societies. The papers contributed to this section of The International Geological Congress have their own merits, but they do not add up to a rounded discussion of the announced subject and most of them really have little or nothing to do with this subject. D. Andrusov (Czechoslovakia) summarizes the tectonic and sedimentational history of the western Carpathians and shows that this region had a long succession of radically changing environmental facies, reflected ecologically by its fossil faunas. L. V. Cepek (Czechoslovakia) discusses coal rifts or graben in western Bohemia and Moravia and demonstrates that the physical development of these depressions influenced the distribution of peat-bogs in them and is reflected in the quality, especially the ash content, of the resulting coals. A. Chavan (France) explains the appearance of tropical molluscs in the late Cretaceous and early Tertiary of northwestern Europe by migration and by increasing warmth of water following opening of the Atlantic basin by continental drift. R. C. Moore (U.S.A.) gives a rather detailed, largely tabular, summary of the evolution of the crinoids and suggests, without being explicit, that the history of that group has been strongly influenced by changes in lands and seaways. V. A. Obruchev (U.S.S.R.) is represented by an unimportant abstract. Finally, K. Zapletal (Czechoslovakia) maintains that major orogenic episodes, progressively displaced in various parts of the world, tend to localize major evolutionary events as to place and time. Although this last paper bears most directly on the problem announced by Dr. Hawkins, it is (to this reviewer) confused and unconvincing.

G. G. SIMPSON

Theory of Hearing; by ERNEST GLEN WEVER. Pp. xii, 484; frontispiece and 137 figs. New York, 1949 (John Wiley & Sons, Inc., $6.00).—In the ten and more years since Stevens and Davis marshalled the facts known about the structure and function of the cochlea into their well known book, much has been learned about audition. Not only was practical knowledge greatly advanced by war-induced research but electrophysiological techniques were extended to single fibres of the cochlear nerve and to other parts of the auditory pathways including the cortical projections. At least 100 research papers from this period are cited in the bibliography of the present

volume which lists over 500. Consequently a book assessing the present status of this area of physiology and psychology is most welcome, particularly one written by a leading research man in the field. This welcome may, however, be somewhat tempered by the fact that Professor Wever has purposely written a book to support a particular theory of hearing, namely the so-called volley theory. Clearly, this of itself is not an indictment. However as this reader progressed through the work, he felt a mounting uneasiness at the continual hammering on this particular theory of cochlear function. The first third of the book, devoted to an excellent exegesis, cast in historical form, of the various theories of hearing, is most stimulating. The ideas are clear and the style effective. The illustrative material, mostly graphs, is good and the book is enlivened by reproductions of several masterly drawings by Max Brödel.

The larger part of the book then turns to the analysis, point by point, of the various data pertinent to hearing in terms of the volley theory. It will be recognized that this theory differs from the almost universally held hypothesis of cochlear physiology, i.e., some form of the place theory, by insisting that pitch recognition and associated phenomena are dependent mainly on the synchrony of stimulus frequency and nerve impulse frequency over a range of several octaves and partly so over 8-9 octaves, place only taking over above 4,000-5,000 cycles per second. Few would deny that such synchrony does occur at the lower end of the auditory spectrum, but few would find the evidence convincing that it is the cue for pitch. Perhaps we should rather look on the slant in Dr. Wever's book as an asset. A good controversy might well evoke just sufficient epinephrine secretion to fill in certain of the wide open gaps in our knowledge of hearing. In that case the volley theory, whether or not it turns out to be the most satisfactory one to account for the facts, will nevertheless have done valuable service.

TALBOT H. WATERMAN

An Index of Mineral Species and Varieties Arranged Chemically, with an alphabetical index of accepted mineral names and synonyms; by Max H. Hey. Pp. xx, 609. London, 1950 (H.M. Stationery Office, Kingsway, W. C. 2; £1-10-0).—The chemically classified list provides a ready answer to anyone inquiring what minerals of a given qualitative chemical composition are known. The classification is based on the commonly accepted primary division of minerals by anions into oxides, sulphides, silicates, etc. followed by secondary subdivisions based upon the metals present. Cross-references are given in many cases where minerals contain several elements or radicals. The classification seems quite workable, as it has no doubt been proved by the author's personal experience at the British Museum. The alphabetical index of mineral names and synonyms is by

far the most complete modern index known to this reviewer; it occupies slightly more than half of the book. Its usefulness is greatly enhanced by references to the literature in which the respective names are defined. This book is clearly essential to any modern mineralogical library. HORACE WINCHELL

Geophysical Survey of Southeastern Netherland; by L. U. DE SITTER and collaborators. Pp. 372; 73 figs., 2 halftone plates; 24 folded "annexes" (in separate container). Maastrict, 1949.—Following the invasion of The Netherlands by the Germans in May, 1940, the geological department of the University of Leyden had to abandon its program of field study in southern Europe, and instead began a concentrated attack on subsurface geology of the home country. Since the greater part of that country is blanketed with young sedimentary deposits, direct information at depth is obtained only in a few mining districts and in scattered areas where drill holes are concentrated. Parties were trained in use of the torsion balance, and 3634 stations were occupied. Maps and sections constructed from the data were destroyed by the retreating Germans in 1944; but, nothing daunted, the research team repeated the labor required to retrieve the loss.

Torsion balance results were supplemented by gravimeter data provided by the Geodetic Commission. Interpretation of these basic materials is expressed in a structure contour map, colored tectonic maps, and geologic structure sections. Where direct check by bore holes is possible, agreement is remarkably good. A pattern of steep faults that divide the bedrock into a mosaic of blocks is brought out particularly well by the gravimetric values. The project has large interest to geologists, as a demonstration of what may be accomplished in tracing known structural features that disappear under alluvial cover, and in mapping additional features by comparative appraisal of gravimetric anomalies.

Although the complete report, comprising 6 parts and an appendix, is printed in Dutch, condensed English translations that occupy the final 100 pages give adequate comprehension of the methods and the results. An alphabetical list of 131 references to pertinent literature adds to the value of the study.

CHESTER R. LONGWELL

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